Published in final edited form as:
Popul Dev Rev. 2011 ; 37(4): 721–747.

Population Momentum Across the Demographic Transition

Laura Blue and **Thomas J. Espenshade**

A typical consequence of the demographic transition—a population's shift from high mortality and high fertility to low mortality and low fertility—is a period of robust population growth. This growth occurs once survival has improved but before fertility has fallen to or below replacement level, so that the birth rate substantially exceeds the death rate. During the second half of the twentieth century, the world experienced unprecedented population growth as developing countries underwent a demographic transition. It was during this period that Nathan Keyfitz demonstrated how an immediate drop to replacement fertility in high-fertility populations could still result in decades of population growth. Building on work by Paul Vincent (1945), he called this outcome "population momentum." Keyfitz wrote, "The phenomenon occurs because a history of high fertility has resulted in a high proportion of women in the reproductive ages, and these ensure high crude birth rates long after the age-specific rates have dropped" (Keyfitz 1971: 71).

For societies today that have not yet completed their demographic transitions, population momentum is still expected to contribute significantly to future growth, as relatively large cohorts of children enter their reproductive years and bear children. John Bongaarts (1994 1999) calculated that population momentum will account for about half of the developing world's projected twenty-first-century population growth. However, even though momentum is a useful concept precisely because of the non-stationary age structures that exist in populations in the midst of demographic transition, no research has examined trends in momentum or documented the highly regular pattern of population momentum across the demographic transition. This article sets out to do so.

We describe the arc of population momentum over time in 16 populations: five in the now-developed world and 11 in the developing world. Because population momentum identifies the cumulative future contribution of today's age distribution to a population's growth and size, adding momentum to our understanding of demographic transition means that we do not treat changes in age distribution merely as a consequence of demographic transition, as is usually the case (Lee 2003). Instead, we also illustrate the impact that these age-distribution changes have themselves had in producing key features of the demographic transition. Age composition exerts an independent influence on crude birth and crude death rates so that for given vital rate schedules, population growth rates are typically highest in those populations with a "middle-heavy" age distribution. During demographic transition (or even during a demographic crisis), any change in a population's age distribution will have repercussions for future population growth potential and future population size.

We also trace the course of two recently defined measures of population momentum. Espenshade, Olgiati, and Levin (2011) decompose total momentum into two constituent and multiplicative parts: "stable" momentum measures deviations between the stable age distribution implied by the population's mortality and fertility and the stationary age distribution implied by the population's death rates; and "nonstable" momentum measures

Figures in this article are available in color in the electronic edition of the journal.

deviations between the observed population age distribution and the implied stable age distribution.

To understand the usefulness of stable and nonstable momentum, consider the case of a population with unchanging vital rates. Over time, stable momentum remains constant as both the stable age distribution and the stationary age distribution are unchanging. In this sense we may consider stable momentum to be the "permanent" component of population momentum; it persists as long as mortality and fertility do not change. In contrast, nonstable momentum in this population gradually becomes weaker and eventually vanishes as the population's age distribution conforms to the stable age distribution. In this sense we may consider nonstable momentum to be the "temporary" or transitory component of population momentum. Of course, most populations exhibit some year-to-year fluctuation in fertility and mortality, so in empirical analyses we commonly observe concurrent changes in both the permanent and the temporary components of momentum. Nevertheless, how overall momentum is composed and what part is contributed by stable versus nonstable momentum have implications for future population growth or decline.1

In showing patterns over time in total population momentum, stable momentum, and nonstable momentum, we pursue three distinct ends. First and most simply, we trace how momentum dynamics have historically unfolded, not only across demographic transitions but also in the midst of fertility swings and other demographic cycles. This is a straightforward task that has not yet been undertaken. Second, we demonstrate some previously ignored empirical regularities of the demographic transition, as it has occurred around the globe and at various times over the last three centuries. Third, although population momentum is by definition a static measure, our results suggest that momentum can also be considered a dynamic process. Across the demographic transition, momentum typically increases and then decreases as survival first improves and fertility rates later fall. This dynamic view of momentum is further supported by trends in stable and nonstable momentum. A change in stable momentum induced by a change in fertility will initiate a demographic chain reaction that affects nonstable momentum both immediately and subsequently.

The demographic transition

Historical roots

Demographic transition first occurred in Europe: in parts of the continent, death rates began a steady decline at some point during the seventeenth or eighteenth century. Because the transitions occurred before the age of reliable vital statistics, the causes of these earliest mortality declines are unclear. By the early nineteenth century, as industrialization took hold and paved the way for even greater advances in health, mortality crises became less common in England, France, and other parts of northern and western Europe (Vallin 1991; Livi-Bacci 2007). Child survival was improving, and life expectancy at birth was inching upward.

As a result of these early mortality declines, the population of Europe began a long period of robust growth, also beginning sometime in the seventeenth or eighteenth century. Although death rates were declining, birth rates remained more or less stable, or at least they declined much more slowly, so that year after year, for decades if not centuries, the number of births exceeded the number of deaths by a substantial margin. In 1700 the population of Europe was an estimated 30 million. By 1900 it had more than quadrupled to 127 million (Livi-Bacci 2007). Europeans also migrated to North America and Australia by the millions. The

[1]Whereas "permanent" and "temporary" might be more intuitive descriptors, the original formulation of the momentum decomposition used "stable" and "nonstable." For consistency, we rely on the latter terminology here.

population continued to grow despite this out-migration, since most of Europe did not experience substantial declines in the number of children per woman until sometime in the late nineteenth or early twentieth century. Fertility reached replacement in many parts of Europe around the mid-twentieth century, and since then has fallen well below replacement in much of the continent.

Demographic transition has occurred much faster in the developing world than it did in Europe. In 1950–55, for example, life expectancy at birth in India was about 38 years for both sexes combined; 15 years later, life expectancy was nearly 47 (United Nations 2009b). Over the same period in Kenya, life expectancy rose from 42 to 51 years, while in Mexico it rose from 51 to 60 (United Nations 2009b). This rapid mortality decline, brought about in part by technology adopted from the West and accompanied initially by little or no decrease in fertility, led not to the long period of steady population expansion that Europe experienced starting more than a century earlier, but rather to rapid population growth, especially in the third quarter of the twentieth century. Following World War II, developing countries grew at an average annual rate of more than 2 percent, with some countries posting yearly population gains of more than 3 or even 4 percent, as in Ivory Coast, Jordan, and Libya (United Nations 2009b).

Unlike in Europe, rapid fertility decline often followed within just a few decades. Although much of sub-Saharan Africa still has fertility well above replacement, most of the rest of the world appears to have completed the demographic transition. Today every country in East Asia has sub-replacement fertility, and even in countries like Bangladesh and Indonesia, once the cause of much hand-wringing among population-control advocates (Connelly 2008: 11, 305), fertility is now barely above replacement (United Nations 2009b). The concept of a demographic transition therefore describes developing-world experience about as well as it seems to have portrayed earlier developed-world experience. The major differences between these two situations are the speed of mortality decline, the speed of fertility decline, and, as has received most attention both then and now, the rate of population growth. Today it is very unusual to see the kind of population doubling times—in some cases less than 20 years —that were so alarming to policymakers and scholars throughout the 1960s and 1970s (Ehrlich 1968).

Stages of the transition

The concept of demographic transition is usually attributed to scholars writing in the second quarter of the twentieth century. These include Adolphe Landry and Warren Thompson, who were first to describe a regular pattern of population change, and later Kingsley Davis and Frank Notestein, who linked patterns of population change to trends in economic and social development (Nam 1994; Ryder 1984). Although researchers have not yet agreed on a comprehensive theory of the causes of demographic transition, empirical investigation has documented both common patterns of demographic experience across populations and heterogeneity, even within a given region, amid those demographic regularities. In particular, populations may differ on the timing of transition (Bongaarts and Watkins 1996), the level of economic and social development at which transition occurs (Watkins 1986), and the cultural and religious milieus in which fertility decisions are made (Caldwell 2006). In this article, therefore, we consider demographic transition as a generalized description of trends rather than a fixed path that all populations must follow.

To highlight some of the more important regularities of demographic transition, scholars have identified “stages” that are thought to be indicative of transitional mortality and fertility (see, for example, Thompson 1929). We use five stylized stages of demographic transition, as shown in Figure 1. The demarcation between any two stages is arbitrary, and we could just as easily have divided the continuum into more stages or fewer. Because no national

NIH-PA Author Manuscript

NIH-PA Author Manuscript

population today remains untouched by improvements in survival, we do not observe any countries in stage 1 of demographic transition. There are, however, many contemporary examples of populations in each of the four later stages.

Our five stages are (1) pre-transition, with high crude death and birth rates leading to low rates of natural increase and fertility high but roughly at replacement; (2) falling death rates with mostly unchanged birth rates, leading to moderate rates of natural increase and fertility above replacement; (3) falling birth and death rates, but with birth rates greatly exceeding death rates, so that fertility is substantially above replacement; (4) low mortality and falling fertility, with fertility slightly above or roughly at replacement; and (5) low birth and death rates, with sub-replacement fertility.

What we call stage 5 of the demographic transition has also been called the “second demographic transition” (van de Kaa 1987). The theoretical basis for this new transition is still debated, and it is by no means clear that a period of sustained below-replacement fertility is inevitable in all populations, or that it should be considered distinct from the first demographic transition (Cliquet 1991; Lesthaeghe and Neels 2002; Lesthaeghe 2010). Still, the fact remains that almost every country that has achieved stage 4 of the transition, characterized by low fertility and low mortality, has also proceeded to sub-replacement fertility. In as much as demographic transition is accepted as a description of empirical regularities rather than as a robust theory to explain underlying causes of population change, the concept of the second demographic transition is no less useful than the first.[2]

Population momentum

For a given population, total population momentum is the size of the hypothetical stationary population achieved by projecting today’s starting population with replacement fertility, zero net migration, and today’s constant death rates, divided by the size of the starting population today. Momentum therefore measures the contribution of age structure to a population’s future growth or decline. With the global net reproduction rate now just barely above 1 (United Nations 2009b), momentum will almost certainly be the main contributor to world population growth through the first half of the twenty-first century.

As noted earlier, Espenshade, Olgiati, and Levin (2011) disaggregated the familiar momentum measure into two (nearly) multiplicative parts: stable momentum and nonstable momentum. Stable momentum is a measure of the deviation between a population’s implied stable age distribution and its implied stationary age distribution. It is essentially a measure of how far fertility is either above or below replacement. Nonstable momentum captures the deviation between a population’s actual age distribution and its implied stable age distribution. It measures how well the observed population age distribution reflects the age pattern that would eventually emerge if current birth and death rates never changed.[3] Together stable and nonstable momentum multiply to produce a close estimate of total momentum that, for each of the 176 United Nations member nations in 2005, deviates from the population momentum statistic as conventionally defined by less than 1.2 percent (Espenshade, Olgiati, and Levin 2011). This article traces total, stable, and nonstable population momentum across time in 16 populations to illustrate the dynamic nature of population momentum.

[2]The stylized picture shown in Figure 1 is an over-simplification. First, not every country has completed a demographic transition. Second, as noted above, some countries took a long time to complete their transitions, whereas others passed through it comparatively quickly. Finally, the picture ignores the fact that populations often experience sharp demographic cycles in mortality and/or fertility at some point during their transitions, as in the influenza epidemic near the end of World War I or the post–World War II baby boom and bust.

Traditional demographic transition eventually leads to a low-mortality, low-fertility population that is either at or close to replacement fertility. For a typical country that follows this path, we expect total population momentum to increase at the beginning of the demographic transition, as the observed age distribution becomes younger than its stationary counterpart, and then to decrease as fertility falls and approaches replacement level. Experience of the last five decades suggests that low-fertility populations may instead stabilize at sub-replacement fertility. In these cases we expect total population momentum to stabilize below 1.

In terms of stable and nonstable momentum, we expect that a population's experience should follow roughly the counterclockwise "swirl" pattern sketched in Figure 2. Consider first a typical developed country, shown by the solid lines in the figure. If the pre-transition population is stationary, then there is no momentum and both stable and nonstable momentum are initially equal to 1. As survival improves and the intrinsic growth rate becomes positive, stable momentum increases and nonstable momentum decreases. The decline in nonstable momentum is the result of an increase in proportions at younger ages in the stable age distribution relative to the observed age distribution. A period of rising stable momentum can last for quite some time, as mortality improvements continue and outpace fertility declines. Then, as the transition enters its later stages, fertility starts to fall more rapidly, causing stable momentum to peak and begin to fall back toward 1. Nonstable momentum increases rapidly because the observed age distribution is partly the residue of previously higher fertility. Survival gains become relatively less important, because they are no longer so heavily concentrated at the youngest ages.[4] Eventually, if the population returns to replacement fertility and stationarity, both stable and nonstable momentum

[3]Stable momentum is called "stable" because, like other stable population concepts, it depends only on a population's current mortality and fertility rates, and not on the observed age distribution. Nonstable momentum instead captures only the deviations from stability, deviations caused by past changes in vital rates. Formally, for all-female populations:

$$\text{Total momentum}=\int_0^{\beta}\frac{c(x)}{c_0(x)}\int_x^{\beta}p(a)m_0(a)da\,dx/A_0$$

$$\text{Stable momentum}=\int_0^{\beta}\frac{c_r(x)}{c_0(x)}\int_x^{\beta}p(a)m_0(a)da\,dx/A_0$$

$$\text{Nonstable momentum}=\int_0^{\beta}\frac{c(x)}{c_r(x)}\int_x^{\beta}e^{-ra}p(a)m(a)da\,dx/A_r$$

where:

$c(x)$ is the observed population proportionate age distribution;

$c_r(x)$ is the stable population proportionate age distribution;

$c_0(x)$ is the stationary population proportionate age distribution;

β is the highest age of childbearing;

r is the stable growth rate;

$p(a)$ is the survival function, a function of age (a);

$m(a)$ is the maternity function, a function of age (a);

$m_0(a)$ is the maternity function in a stationary population, obtained by normalizing the maternity schedule, $m(a)$, by the net reproduction rate;

A_0 is the mean age at childbearing in the stationary population; and

A_r is the mean age at childbearing in the stable population.

converge again on 1. Instead, if the population experiences a second demographic transition, stable momentum will come to rest below 1.

The wider arcs to the momentum swirls in developing countries are illustrated by the dashed lines in Figure 2. Developing countries may complete their transitions faster, because they can adopt existing developed-world technologies for improved survival and fertility control rather than inventing these technologies anew, as the now-developed countries did in the nineteenth and twentieth centuries. Owing to staggered innovation, diffusion, and/or use, methods to control mortality typically become available before effective methods of limiting births. The ability to draw upon developed-world technologies can produce in turn more pronounced increases first in stable momentum and later in nonstable momentum, leading to potentially bigger swirls than those observed in many developed countries.

Data and methods

We use historical data and projected estimates of mortality, fertility, and population size by age to calculate total momentum, stable momentum, and nonstable momentum for 16 countries as these countries undergo their demographic transitions. We have chosen the countries to exemplify various stages of demographic transition. They are listed in Table 1 along with the basic demographic indicators that we used to classify them by stage.

Although other populations would show broadly similar trends and patterns, we selected these countries using the following criteria: (a) together, the 16 populations cover a range of transition stages; (b) they span the globe, with most major regions of the world represented; and (c) most populations have experienced relatively little emigration or immigration, so that changes in momentum primarily reflect changes in vital rates rather than migration patterns.[5] This last criterion was hardest to satisfy among developed-country populations, and it is the main reason we do not include developed countries from either North America or Oceania. We use projections of future mortality, fertility, and population size in addition to historical data, so that we may draw conclusions about the course of momentum across populations' complete (or almost complete) demographic transitions, even in those countries where transition has just begun.

We use two main sources of data for this project: the 2008 Revision of the United Nations's *World Population Prospects* (United Nations 2009b) and the Human Mortality Database (HMD)(2010). For each calculation of total momentum, stable momentum, and nonstable momentum, we need population counts by sex and age, survivorship proportions by sex and age, and age-specific fertility rates by sex of the infant. We use UN and HMD estimates for the period 1950–2010. All projected values of mortality, fertility, and population size beyond 2010 are the UN's medium variant. To extend our data farther back in time, we use data from the HMD for four European populations before 1950. Where age-specific fertility

[4]The momentum effects of mortality decline depend on which age groups are most affected by the change in death rates. A useful starting point is to consider a decline in death rates by the same absolute amount at every age. This "neutral" change in mortality will have no impact on either the observed or the stable age distribution, but the stationary population will be flatter and older. Both total and stable momentum should increase, and there should be no change in nonstable momentum. Guillot (2005) has decomposed total momentum into two multiplicative factors: (a) the direct effect of improvements in cohort survivorship and (b) fluctuations in annual numbers of births.

[5]Migration complicates the analysis of momentum. Migrants entering or leaving can alter the age distribution of a population. The typical age pattern of migration rates has a peak among young children and a larger peak among young adults in their early 20s corresponding to entry into the labor force (Rogers and Watkins 1987). Immigrant-receiving countries would therefore tend to have relatively young age distributions, which would increase total momentum, other things constant. Opposite effects could be felt in sending countries. Depending on their volume and behavior, immigrants might also shift a country's mortality and fertility schedules. More than 215 million people, or about 3 percent of the world's population, are estimated to live outside their country of birth (United Nations 2009a). This is not a particularly large percentage, but countries vary substantially in the foreign-born proportions in their populations (Organisation for Economic Co-operation and Development 2010).

data before 1950 are not available, we model age patterns of childbearing using model fertility schedules and estimates of total births by sex of the infant.

We describe our data and procedures in the Appendix. Data quality varies among the 16 populations and over time within each population. Data in the HMD are vetted for likely reporting errors and inconsistencies; thus, for the European countries, even the historical data are likely to be quite accurate, based on relatively complete censuses and death registers (Human Mortality Database 2010). For the developing countries, data sources are fewer. Particularly for the least-developed countries and for the earliest period of analysis around 1950, UN estimates of population counts and fertility rates are based on sporadic records, such as infrequent national censuses (adjusted for incomplete coverage) and Demographic and Health Surveys (United Nations 2009b). Death rates are often modeled using Coale–Demeny (1983) life tables, adjusted where appropriate for HIV/AIDS (United Nations 2009b). This variation in data quality is inevitable for any project that assesses historical trends beyond a handful of highly developed countries.

We calculate total population momentum, stable momentum, and nonstable momentum for every five years of data in a population. The final momentum calculation is for 2045, using projected fertility and mortality rates for 2045–50. We show results for females only, partly because the underlying analytic work is based on single-sex populations. Results for males would in most cases look very similar.6

The three momentum quantities are defined as follows (see Figure 3):

Total population momentum is the ratio of the size of the eventual stationary population (S_1), given the population's constant vital rates at replacement, to the size of the initial observed population (P).

Stable momentum is the size of the eventual stationary population (S_2) that would result from applying a given population's constant vital rates at replacement to the population's stable-equivalent population, divided by the size of the stable-equivalent population (Q).

Nonstable momentum is the ratio of the size of the stable-equivalent population (Q) to the size of the initial observed population (P).

The quantities in Figure 3 are generated as follows. We calculate the size of the eventual stationary population (S_1) by projecting forward each country/period observation (for example, a country's population in 1950 using vital rates from 1950–54) for 300 years, using a Leslie matrix that contains its replacement fertility rates and its life-table survivorship proportions. A projection interval of 300 years is long enough to permit a population to reach equilibrium. We calculate the stable-equivalent population (Q) by projecting the initial population forward 300 years using fertility and mortality rates estimated for the observation period, and then back-projecting 300 years using the same vital rates to yield a new stable population. We calculate S_2 by projecting the stable-equivalent population (Q) for 300 years using mortality and replacement fertility estimated for the observation period. Replacement fertility rates are generated by dividing age-specific fertility rates by the net reproduction rate. We perform all calculations in STATA 11.7

6Death rates within a population typically differ by sex, but they rarely vary sufficiently to yield markedly different momentum calculations. One exception, that of France during World War I, is discussed below. The effects of son preference and sex selection in China and elsewhere, however, could produce lower values of total momentum for females than for males. In this case, there is likely to be a more youthful age distribution for males than for females because of higher birth rates for boys, whereas males may have a flatter stationary age distribution if female infants experience higher mortality than males through infanticide or other means. For more information, see Hvistendahl (2011) and Jiang, Li, and Feldman (2011).

Results and discussion

Total momentum

As expected, the general historical pattern is for total population momentum to increase during the early stages of demographic transition, and then to fall as fertility rates decline. Total momentum for the 11 developing-country examples is shown in Figures 4, 5, and 6, with results grouped by stage of demographic transition. Momentum patterns for the developed countries, namely Japan and the four European populations, are displayed in Figure 7.

Results for all 11 developing-world populations are quite similar. There is slight variation in starting levels of fertility and mortality in 1950, but the main difference among the three stages appears to be the timing of transition. Momentum generally peaks somewhere between 1.4 and 1.6 for all developing-world populations, but this peak occurs around 1980 for the stage 4 countries and around 1995 for stage 3 countries. For stage 2 countries, the peak is projected to arrive around 2015. Two sub-Saharan African countries, Kenya and South Africa, are outliers, with pronounced momentum declines in the 1980s and 1990s. These declines are due partly to fertility reductions, as we might expect in the middle of a demographic transition, but also to a rapid increase in mortality for women of childbearing age, caused by the burgeoning HIV/AIDS epidemic (Bongaarts, Pelletier, and Gerland 2011).

In the developed world (Figure 7) we see more variation. Data are available for a much longer period, so that in Sweden we can trace the course of momentum from what appears to be the pre-transition era. In eighteenth-century Sweden there is no apparent trend to momentum, with fluctuations attributable mostly to short-term swings in vital rates caused, most likely, by natural variation in disease cycles and by demographic crises like famine in the early 1770s. Starting in the nineteenth century, momentum begins to increase steadily, and records from Belgium and Finland later in that century suggest that these countries underwent a similar process. As expected, momentum peaks at a much lower level in the European countries than in the developing countries, with a maximum somewhere around 1.2 rather than 1.4 or 1.6.

France does not follow the usual pattern of momentum. This observation is consistent with findings of the European Fertility Project (Watkins 1986), which showed that demographic transition in France was qualitatively different from transitions observed elsewhere. Fertility and mortality declined more or less concurrently in France, instead of mortality decline preceding fertility decline. As a result, momentum does not have the characteristic mid-transition peak we expect from the stylized facts of demographic transition.

Belgium, Finland, and Sweden appear to complete their demographic transitions sometime around the middle of the twentieth century, with fertility falling approximately to replacement or below. After World War II, however, European countries (this time including France) experience a second momentum boom, in some cases with higher momentum peaks than those observed during the demographic transition itself. This increase in momentum coincides with the baby boom in Europe and North America, and to some extent with impressive postwar mortality gains in the war-affected countries. Fertility rates fall again in the following period, driving momentum back down as the second demographic transition takes hold.

[7]The values for total, stable, and nonstable momentum at a given point in time are determined by assuming that age-specific death rates stay constant into the indefinite future. However, our momentum calculations across time are built on United Nations (2009b) past estimates and future projections of mortality and therefore take into account gradually improving survival chances.

Japan stands out from the other developed countries. The data range is shorter, so that it is not apparent when Japan's demographic transition began. It seems likely that Japan experienced a relatively rapid demographic transition, since its postwar momentum peak is as high as those seen during the transition in today's developing countries. Sharp fertility declines have followed, however, so that today Japan has by far the lowest total population momentum among the countries analyzed here.

Stable and nonstable momentum

We show historical and projected patterns of stable and nonstable momentum in Figures 8 to 15. The clear relationship that we observe between changes in stable and nonstable momentum strongly supports the dynamic view of population momentum as a process that unfolds over time. If stable momentum falls because of a fertility decline, then nonstable momentum invariably increases at the same time (assuming constant or slowly changing mortality). This instantaneous increase occurs because the stable age distribution is now older, so that the proportion of the observed population entering the childbearing years increases relative to the stable age distribution.

A decline in fertility also affects future nonstable momentum. It can take many years for a population's age distribution to equilibrate to a new fertility regime, and until it does the observed population remains younger than the stable population. In the meantime, therefore, nonstable momentum tends to stay above 1. This means that we should not expect sharp fertility declines to lower total population momentum immediately. Rather, fertility reductions convert stable momentum to nonstable momentum, which then gradually disappears over many years (assuming roughly constant vital rates thereafter).

The phenomenon of rising nonstable momentum as stable momentum falls is highly regular. It occurs in the top-right portion of the momentum swirl where total momentum is typically greatest, and it is apparent in all of the 16 populations analyzed. Although we observe fewer instances of stable momentum rising due to fertility *increases*, where this happens (most often among populations that now have below-replacement fertility) we again find predictable changes in nonstable momentum: as stable momentum rises, nonstable momentum falls.

The counterclockwise swirl expected from Figure 2 is most apparent in the developing-world countries (Figures 8 to 10), which have largely avoided major swings in fertility, at least since World War II. For 1950, we calculate stable momentum at well above 1 in all of these countries, suggesting that the demographic transition was already underway when the United Nations began publishing worldwide data on it. This means that we do not see the very beginnings of the swirl in these countries. However, the rest of the pattern is more or less the one laid out in Figure 2. Stable momentum typically increases, before a later period of falling stable momentum and rising nonstable momentum. Eventually, if UN projections hold true (at least for the stage 4 countries), nonstable momentum will begin to fall as well, as a population converges to a long-run equilibrium and the transient, nonstable component of total momentum disappears. The projections do not show these countries becoming stationary, however, because the United Nations no longer projects that populations will converge on replacement fertility, and because mortality improvements are projected to continue throughout the projection period. Instead, as the panels in Figure 10 indicate, fertility is projected to stabilize below replacement with stable momentum less than 1. In other words, the second demographic transition is projected to spread to many of the world's developing countries.

Results from the developed world, shown in Figures 11 to 15, correspond approximately to the patterns shown in Figure 2, but only until about 1950, before the baby boom. As anticipated, increases in stable momentum are typically small during the countries' demographic transitions, and the transitions usually last many decades. For example, in Sweden (shown in Figure 15) it takes roughly 120 years for stable momentum to increase from somewhere around 1 to 1.2. This gives a large number of data points in a very small area on the graph. Stable momentum later falls and nonstable momentum rises relatively rapidly during the early twentieth century in Belgium, Finland, and Sweden, as fertility declines set in.

These three countries returned to replacement fertility around the middle of the twentieth century. Since then, however, they have experienced substantial fluctuations in fertility rates: the baby boom followed by fertility declines and also some baby boom echoes. This produces a momentum pattern unlike that described in Figure 2—one characterized by a series of sharp reversals in the swirl along a northwest–southeast diagonal. As fertility swings become less common over time, stable momentum once again falls, this time to well below 1 as fertility stabilizes below replacement and nonstable momentum begins to fall back toward 1.

France (Figure 13) is once again an outlier, with very little change in stable or nonstable momentum during the country's nineteenth-century demographic transition. As before, France exhibits an unusual pattern because declines in French fertility and mortality were mainly concurrent, whereas elsewhere mortality decline preceded fertility decline. The swirl that appears for France is a product not of what we generally consider the demographic transition, but instead of the baby boom and of rapid improvements in adult mortality immediately following World War II. Stable momentum peaks in 1960; nonstable momentum peaks a generation later in 1990. The left-most point in Figure 13, labeled 1916 and corresponding to the five-year period beginning in that year, does not reflect demographic transition so much as demographic crisis. This point shows very low stable momentum and very high nonstable momentum. Both are caused by unusually low fertility during World War I and by unusually high mortality during the influenza pandemic of 1918–19. Because our analysis here is for females only, the impact of the war is seen mostly in low fertility rather than high mortality, although low fertility is surely due in part to the exceptional mortality among young men who might otherwise have been fathers.

Results for Japan (Figure 14) are unlike those of any other developed country. This is partly because data collection in Japan begins so much later than it does in Europe, so that we observe Japan only in what may be the last stages of its demographic transition, with moderately high but falling stable momentum and rising nonstable momentum. Following World War II, Japan has also shown the most severe fertility collapse of any of the developed countries reviewed here, with persistently low and falling fertility rates throughout the last decades of the twentieth century. This leads to total momentum well below 1 in 2005–10. Momentum below 1, of course, means that if fertility were to rebound to replacement immediately, total population size would still decrease before becoming constant.

Conclusions

We have traced past and projected future population momentum in 16 countries around the world, all of which exhibit broadly similar trends in momentum throughout their demographic transitions, irrespective of the timing of transition or its location. Except for France, all of the countries appear to experience an increase in total population momentum as the demographic transition begins and then a decrease as the transition concludes. All countries, again with the exception of France, experience an increase in stable momentum as

NIH-PA Author Manuscript

NIH-PA Author Manuscript

the transition begins, and a decline in stable momentum with an increase in nonstable momentum as the transition progresses.

The examples presented help to elucidate four main points. First, they demonstrate the dynamic relationship between stable and nonstable momentum. Our results show that changes in stable momentum are typically accompanied by, and indeed induce, predictable changes in nonstable momentum, warranting the view of momentum as a process that unfolds over time and not simply as a measure for a particular moment.

Second, a sudden decline in fertility should not be expected to produce an immediate drop in total momentum. Instead, the decline converts stable momentum into nonstable momentum. In other words, fertility declines lower the permanent component of total population momentum that would persist indefinitely if vital rates never changed again, while simultaneously raising the transient or ephemeral component, which declines over several years following a fertility change. Thus, fertility declines set the stage for gradual reductions in overall momentum.

Third, our review of momentum over time reinforces the conclusion of Princeton's European Fertility Project that amid clear regularities in populations' demographic transitions, much room remains for heterogeneity. Of the 16 countries examined, 15 show essentially the same swirl pattern connecting stable and nonstable momentum. However, there are differences in the timing of the transitions. Moreover, given the long time frame over which a transition typically occurs, it is quite common for populations to be deflected from the stylized transition pattern by a demographic crisis. We see such demographic crises in famines, as in Sweden in the 1770s; in wars, as in France particularly during World War I; and in epidemic disease, as with HIV/AIDS in Kenya and South Africa today.

Fourth, we show the effect of projected fertility declines on countries' potential for population growth. In its 2008 medium-variant series, the United Nations assumes sub-replacement fertility by mid-century for a number of the developing countries considered here, including Argentina, Brazil, Egypt, Haiti, India, Indonesia, South Africa, and Turkey. If the second demographic transition does indeed spread to today's nearly developed countries, worldwide population momentum will soon fall below 1. Because total momentum below 1 means that a population will shrink for a period even if its fertility is set at replacement, this last finding suggests that if the 2008 UN projections are roughly accurate even for just the next few decades, the world can probably expect substantial global population contraction beginning in the second half of the twenty-first century.

Acknowledgments

Partial support for this research was provided by grants from the Eunice Kennedy Shriver National Institute of Child Health and Human Development (grant #5R24HD047879), from the National Institutes of Health (grant #5T32HD007163), and from the National Science Foundation Graduate Research Fellowship Program (grant #DGE-0646086). We thank Analia Olgiati for providing a STATA tool to run our momentum calculations, Chang Chung for his advice on graphs and data presentation, and the Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat for preparing special tabulations of results from its 2008 Revision of *World Population Prospects*.

Data appendix

We use historical and projected data from 16 countries: Argentina, Belgium, Brazil, Egypt, Ethiopia, Finland, France, Haiti, India, Indonesia, Japan, Kenya, Nigeria, South Africa, Sweden, and Turkey. Results are presented for females only.

Data for 1950–2045

For the period 1950–2045, we take estimates and projections for all 16 populations from the United Nations' *World Population Prospects* 2008 Revision (United Nations 2009b). These data include female population size by age, female age-specific mortality, age-specific fertility (for infants of both sexes), and the sex ratio at birth. All projected values (from 2010 to 2045) are the UN's medium-variant estimates.

Because our momentum calculations use survivorship ratios calculated from the "life-years lived" column of the life table (that is, ${}_nL_x$), the Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat provided us with special tabulations of unpublished ${}_nL_x$ values from the 2008 Revision for all 16 of our populations. There were a few periods for which age-specific mortality data were not available: 1950–1964 in South Africa, 1950–1984 in Turkey, and 1950–1994 in Finland and Sweden. For these missing periods, we took mortality data for Finland and Sweden from the Human Mortality Database (see the section below on "Pre-1950 data for European countries" for a description of these data). For South Africa and Turkey, we estimated missing ${}_nL_x$ values for each five-year period by fitting the UN estimate of female life expectancy at birth to a Coale–Demeny model West life table (Coale and Demeny 1983).

We have UN estimates and projections for age-specific fertility rates in all 16 countries for 1950–2045. In some cases the UN Population Division again provided special unpublished tabulations. We convert age-specific fertility rates into age-specific rates for female births only by dividing each rate by the UN estimate of the sex ratio at birth (plus 1) in that population during the period in question. This assumes the sex ratio at birth does not vary by age of the mother.

In all the UN data, female population size is given in five-year age groups as a point estimate every five years (for example, 1950, 1955, and so on). Mortality and fertility data are also given for five-year age groups, but data on mortality, fertility, and the sex ratio at birth span five-year time periods (for example, 1950–54, 1955–59, and so on). For this reason we calculate all momentum measures by applying fertility and survivorship measured in a given five-year period to the population size measured at the beginning of this period. For instance, we apply the fertility and survivorship rates from 1950–54 to the population observed in 1950.

Pre-1950 data for the European countries

For the four European countries, which have long histories of mortality, fertility, and census records, we take pre-1950 historical data from the Human Mortality Database at www.mortality.org (Human Mortality Database 2010). These countries are Belgium, for which data on female population size by age group, female death rates by age group, and total number of female births exist from at least 1841; Finland, with data from 1878; France from 1816; and Sweden from 1751. (Belgium is missing data for the years 1915 to 1918, presumably because records could not be accurately kept during World War I. These years are omitted from the analysis.) For consistency across the 16 countries, we use HMD data only until UN data are available, starting in most cases in 1950. To parallel the UN data and to reduce noise in our data, we average ${}_nL_x$ values for five-year age groups over five-year periods (for example, females aged 10–14 in 1751–55). However, because we have population counts for every year, we apply these five-year average rates to the five-year average female population size. The HMD limits its data to populations with near-complete death registration and census counts and provides the best available historical data on mortality and population census counts for the four European countries.

NIH-PA Author Manuscript

NIH-PA Author Manuscript

To the best of our knowledge, there are no reliable national data on age-specific fertility rates until well into the twentieth century. Once these fertility data are available for our national populations, starting in the 1930s and 1940s, we use any pre-1950 age-specific fertility rates recorded in the League of Nations *Statistical Yearbooks* and, later, in the United Nations *Demographic Yearbooks*. Where data are missing for these countries for a year, we calculate the five-year average fertility rates from the other years available. For example, the *Demographic Yearbooks* do not include age-specific fertility rates for Finland in 1942. We thus calculate Finnish fertility for the period 1938–42 as the average of the rates from 1938, 1939, 1940, and 1941. We convert fertility rates to fertility rates for female births only by assuming a sex ratio at birth of 105 males per 100 females.

For historical calculations of momentum before the advent of fertility records, age-specific fertility rates must be modeled. We do this based on the total number of female births, which are recorded in the HMD, but we fix the age pattern of childbearing. The *level* of fertility in each population will thus vary according to the total number of female births, but we assume the *age pattern* of fertility remains constant.

Because data on nineteenth-century national age patterns of fertility are very limited, we tried two approaches. The first was to model nineteenth-century fertility (and, in the case of Sweden, to model eighteenth-century fertility as well) assuming that the age pattern of childbearing had been, throughout the relevant historical period, the same as it was in the first year in which age-specific fertility rates were recorded by the League of Nations. Because these records were taken from the 1930s and 1940s, a time of economic depression, they reveal an age pattern consistent with relatively late marriage and late mean age at first birth—perhaps implausibly late for the preceding centuries. Alternatively, therefore, our second approach was to model fertility using the age pattern of the natural fertility schedule among married women (Henry 1961). This led to extremely high fertility at the youngest ages, implying very early marriage and early mean age at first birth. Experimentation shows that the momentum calculations are relatively insensitive to the choice of age pattern used—with results differing by no more than 0.5 percent in the vast majority of cases. Once the level of fertility is known, the age pattern matters little except in extreme situations.[8] The results in this article are shown for the model that fixes the age pattern of fertility to the pattern in actual early fertility records.

References

Bongaarts, John. Population policy options in the developing world. Science. 1994; 263(5148):771–776. [PubMed: 8303293]

Bongaarts, John. Population momentum. In: Andrew, Mason; Merrick, Thomas; Shaw, Paul, editors. Population Economics, Demographic Transition, and Development: Research and Policy Implications. Washington, DC: IBRD/World Bank; 1999. p. 3-15.World Bank Working Paper.

[8]Once the level of fertility—that is, the total number of births—is set, the age pattern matters for momentum only if the population's age distribution is extremely irregular. Because the European countries in this article had demographic transitions lasting for several generations, the population age distributions before 1940 do not differ substantially from quasi-stable age distributions. There are two notable exceptions, however. One is Belgium between the two World Wars. Because of the very small cohort born during World War I, the age distribution of women yet to finish childbearing is highly unusual throughout the 1920s and 1930s—the years just before age-specific fertility records are available. In some of these years the two sets of calculations of total momentum in Belgium, based on two different model age patterns of fertility, differ by as much as 0.67 percent; the difference between the two sets of calculations for stable momentum and nonstable momentum differ by as much as 6 percent. The largest absolute difference that we calculate between the two different sets of total momentum results is for Finland in 1889—a difference of 1.25 percent. HMD data suggest that a very sharp temporary drop in fertility accompanied the devastating Finnish famine of 1866–68, so that the cohort born during these years was extraordinarily small compared to cohorts that came before or after it. The largest difference between the two sets of calculations of stable and nonstable momentum is 2 percent and 2.8 percent, respectively, in 1879.

Bongaarts, John; Pelletier, François; Gerland, Patrick. Global trends in AIDS mortality. In: Richard, Rogers; Crimmins, Eileen, editors. International Handbook of Adult Mortality. Dordrecht, Netherlands: Springer; 2011. p. 171-183.

Bongaarts, John; Watkins, Susan Cotts. Social interactions and contemporary fertility transitions. Population and Development Review. 1996; 22(4):639–682.

Caldwell, John C. Demographic Transition Theory. Dordrecht, Netherlands: Springer; 2006.

Cliquet, Robert. The Second Demographic Transition: Fact or Fiction?. Strasbourg: Council of Europe; 1991.

Coale, Ansley J.; Demeny, Paul. Regional Model Life Tables and Stable Populations. Second Edition. New York: Academic Press; 1983.

Connelly, Matthew. Fatal Misconception: The Struggle to Control World Population. Cambridge, MA: The Belknap Press of Harvard University Press; 2008.

Ehrlich, Paul. The Population Bomb. New York: Ballantine Books; 1968.

Espenshade, Thomas; Olgiati, Analia; Levin, Simon. On nonstable and stable population momentum. Demography. 2011; 48(4):1581–1599. [PubMed: 21948106]

Guillot, Michel. The momentum of mortality change. Population Studies. 2005; 59(3):283–294. [PubMed: 16249150]

Henry, Louis. Some data on natural fertility. Eugenics Quarterly. 1961; 8:81–91. [PubMed: 13713432]

Human Mortality Database. [Data downloaded July 2009] University of California, Berkeley (USA) and Max Planck Institute for Demographic Research (Germany). 2010. Available at «www.mortality.org» or «www.humanmortality.de».

Hvistendahl, Mara. Unnatural Selection: Choosing Boys over Girls and the Consequences of a World Full of Men. New York: Public Affairs; 2011.

Jiang, Quanbao; Li, Shuzhou; Feldman, Marcus W. Demographic consequences of gender discrimination in China: Simulation analysis of policy options. Population Research and Policy Review. 2011; 30(4):619–638.

Keyfitz, Nathan. On the momentum of population growth. Demography. 1971; 8(1):71–80. [PubMed: 5163984]

Lee, Ronald. The demographic transition: Three centuries of fundamental change. Journal of Economic Perspectives. 2003; 17(4):167–190.

Lesthaeghe, Ron. The unfolding story of the second demographic transition. Population and Development Review. 2010; 36(2):211–251. [PubMed: 20734551]

Lesthaeghe R, Neels K. From the first to the second demographic transition: An interpretation of the spatial continuity of demographic innovation in France, Belgium and Switzerland. European Journal of Population. 2002; 18(4):325–360.

Livi-Bacci, Massimo. A Concise History of World Population. Fourth Edition. Malden, MA: Blackwell Publishing; 2007.

Nam, Charles. Understanding Population Change. Itasca, IL: FE Peacock Publishers; 1994.

Organisation for Economic Co-operation and Development. OECD Factbook 2010: Economic, Environmental and Social Statistics. OECD Publishing; 2010.

Rogers, Andrei; Watkins, John. General versus elderly interstate migration and population redistribution in the United States. Research on Aging. 1987; 9(4):483–529. [PubMed: 3438564]

Ryder, Norman B. Obituary: Frank Wallace Notestein (1902–1983). Population Studies. 1984; 38(1): 5–20. [PubMed: 22087619]

Thompson, Warren S. Population. American Journal of Sociology. 1929; 34:959–975.

United Nations. International Migration 2009. New York: 2009a. Data online at «http://www.un.org/esa/population/publications/2009Migration_Chart/ittmig_wallchart09.pdf».

United Nations. World Population Prospects: The 2008 Revision. New York: 2009b. Data online at «http://esa.un.org/unpp/index.asp».

Vallin, Jacques. Mortality in Europe from 1720 to 1914: Long-term trends and changes in patterns by age and sex. In: Roger, Schofield; Reher, David; Bideau, Alain, editors. The Decline of Mortality in Europe. Oxford: Clarendon Press; 1991. p. 38-67.

van de Kaa, Dirk. Europe's second demographic transition. Population Bulletin. 1987; 42(1):1–59. [PubMed: 12268395]

Vincent, Paul. Potentiel d'accroissement d'une population. Journal de la Société de Statistique de Paris, 1re Série, Janvier–Février. 1945; 86(1–2):16–39.

Watkins, Susan. Conclusions. In: Ansley, J. Coale; Watkins, SusanCotts, editors. The Decline of Fertility in Europe: The Revised Proceedings of a Conference on the Princeton European Fertility Project; Princeton University Press; 1986. p. 420-450.

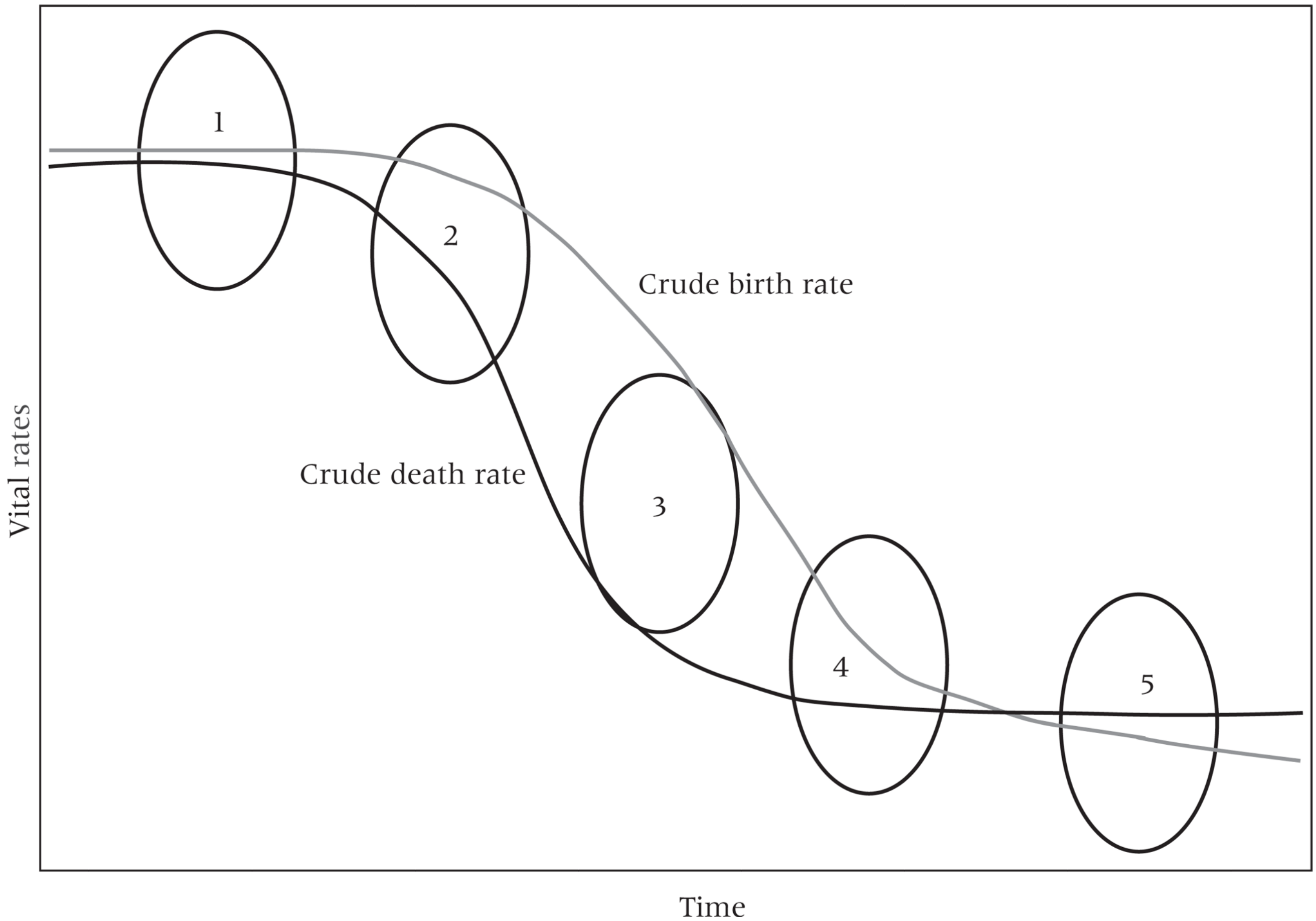

FIGURE 1. Five stages of a stylized demographic transition

NOTE: Numbered stages represent 1. pre-transition, 2. early transition, 3. mid-transition (maximum rate of natural increase), 4. late transition, 5. second demographic transition.

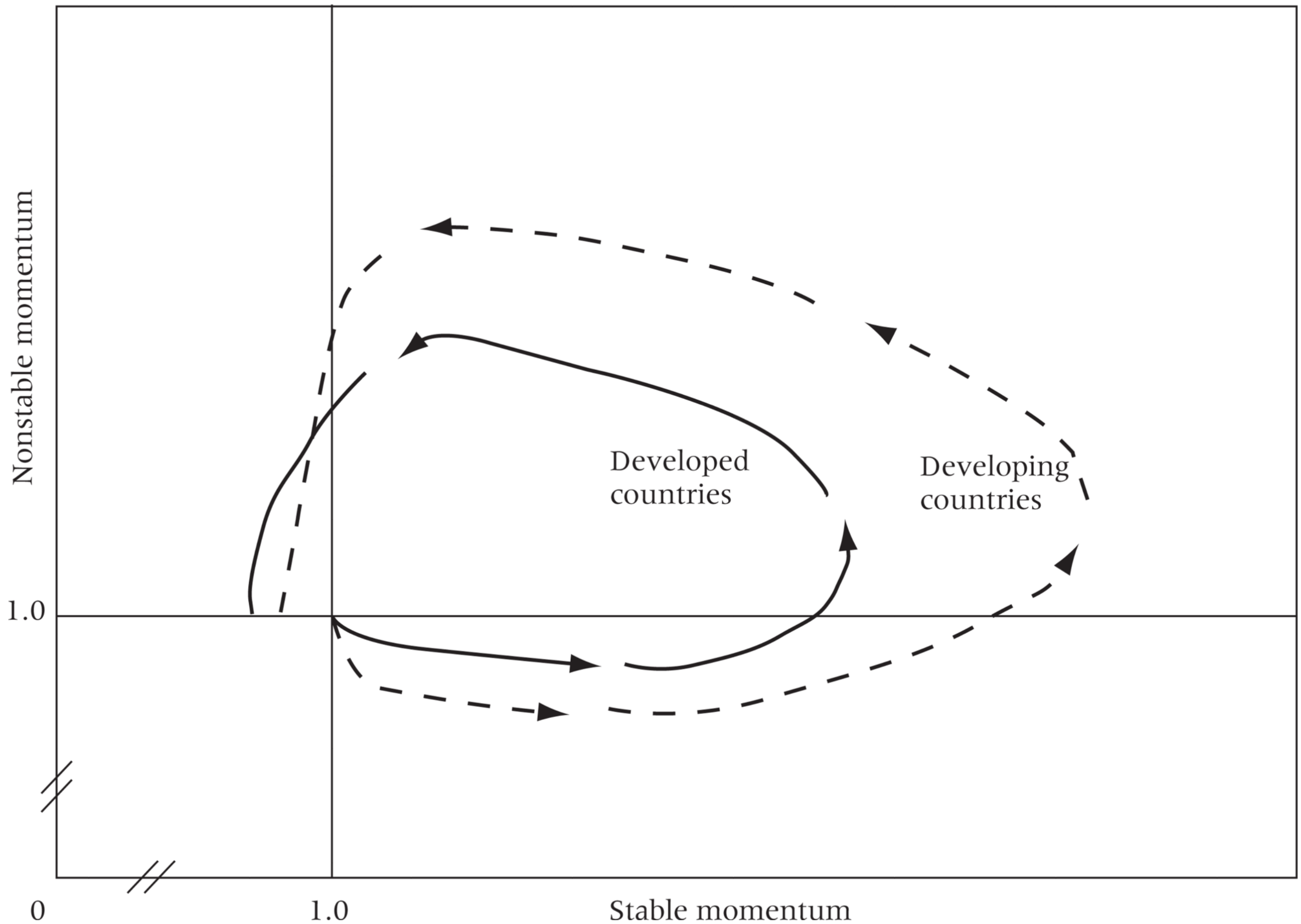

FIGURE 2. Expected stable and nonstable population momentum across a stylized demographic transition in developed and developing countries

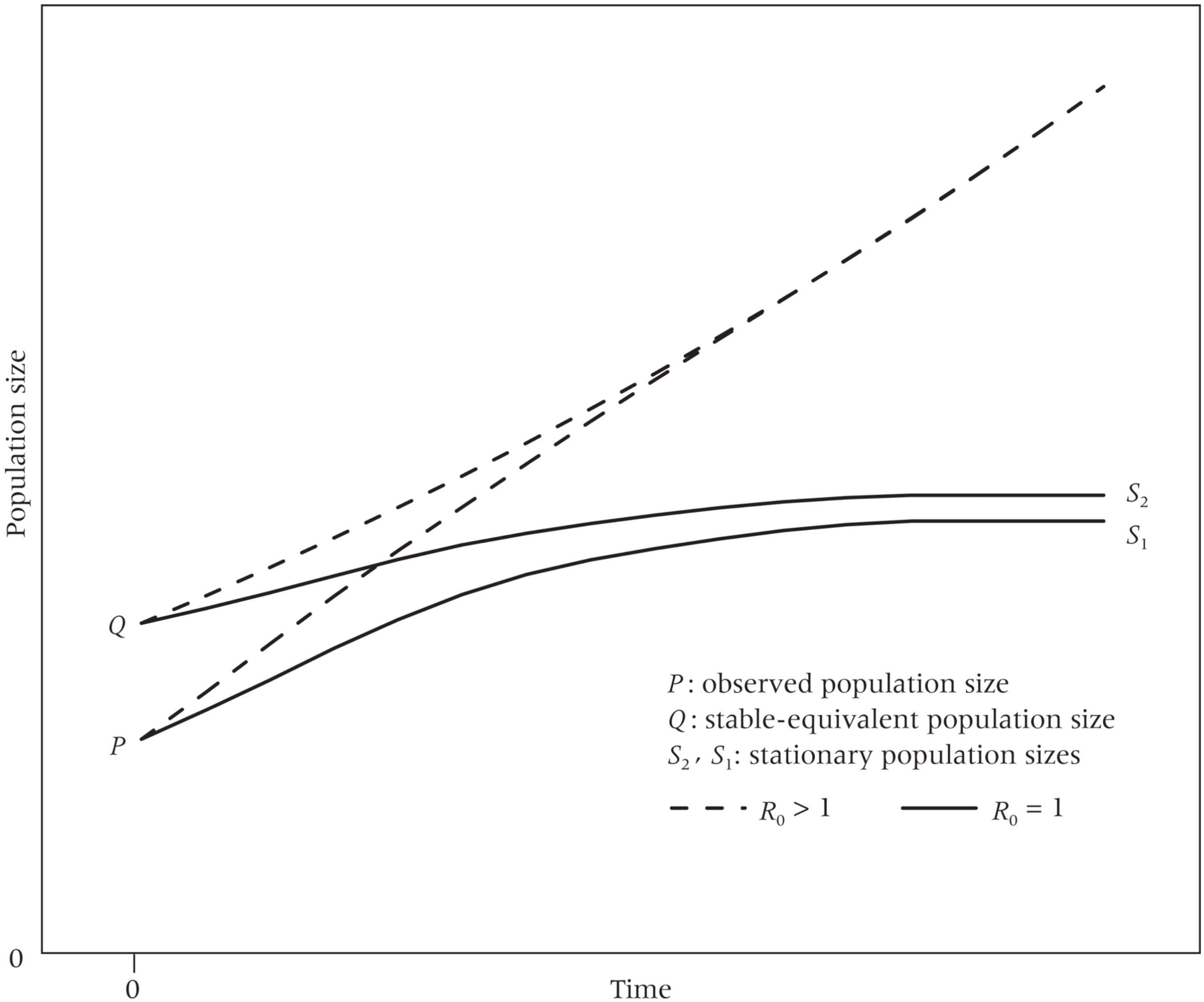

FIGURE 3. Calculating total, stable, and nonstable population momentum
NOTE: R_0 is the net reproduction rate.
SOURCE: Espenshade, Olgiati, and Levin (2011).

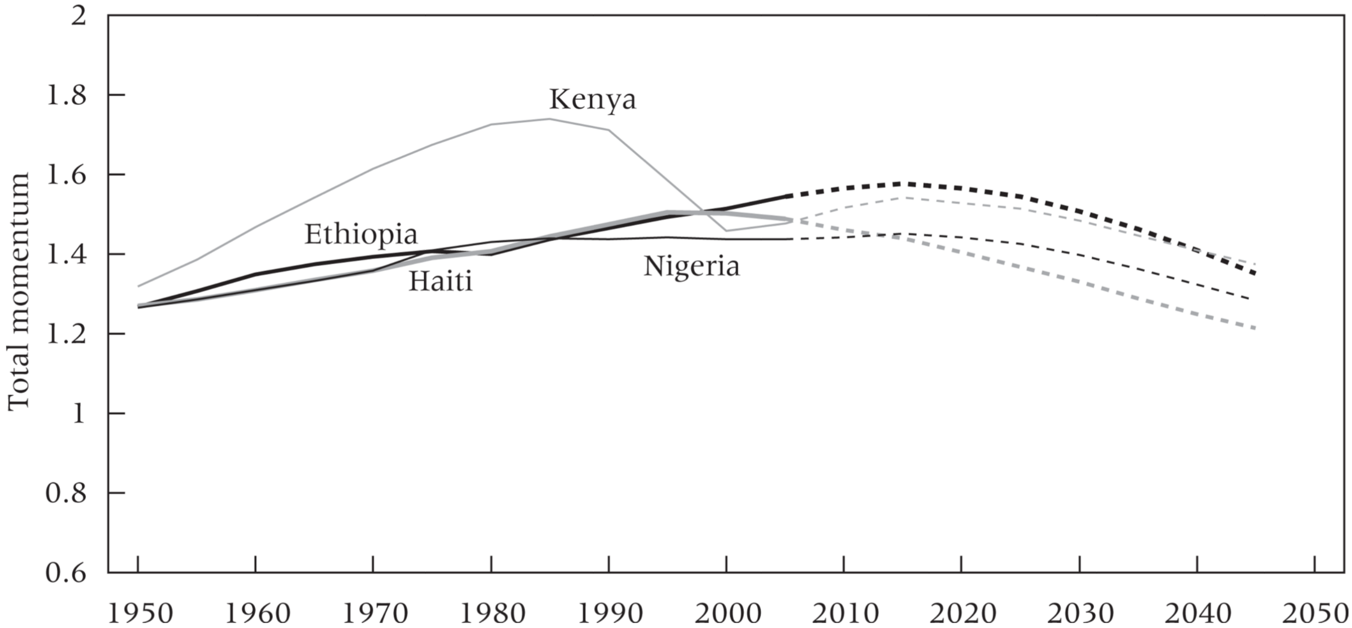

FIGURE 4. Total population momentum in four developing countries, stage 2 of the demographic transition, 1950–2045

NOTE: Dotted lines represent projected trends after 2005–2010.

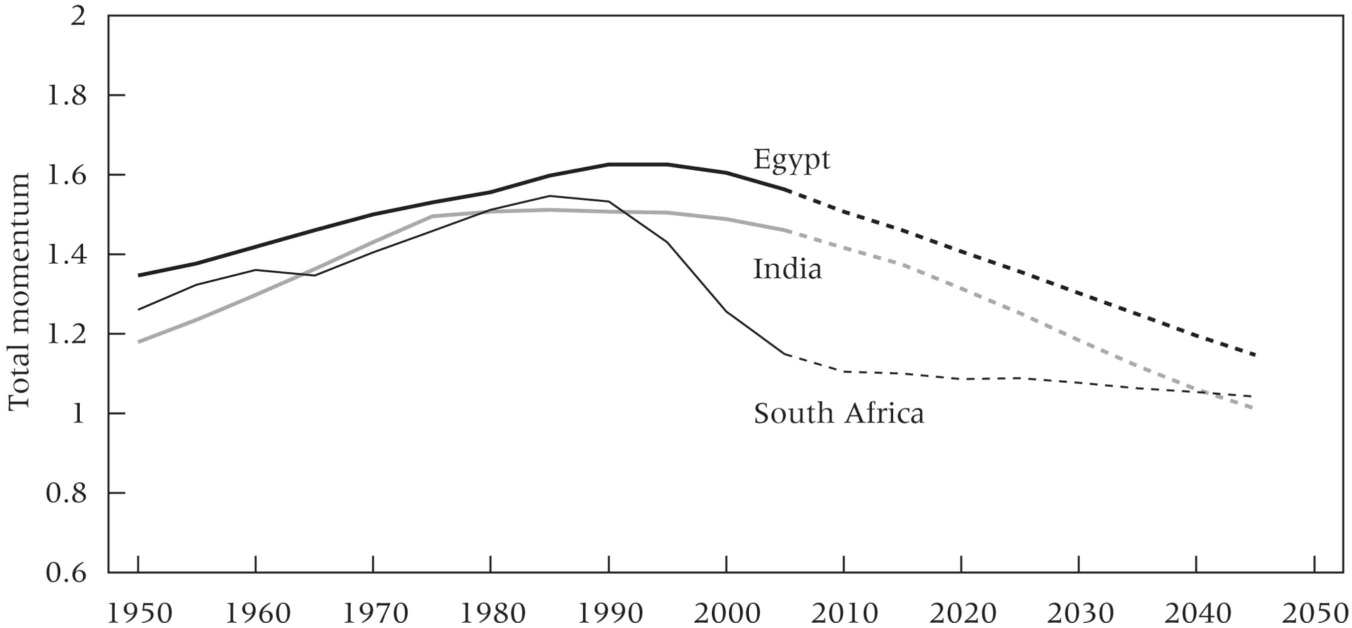

FIGURE 5. Total population momentum in three developing countries, stage 3 of the demographic transition, 1950–2045

NOTE: Dotted lines represent projected trends after 2005–2010.

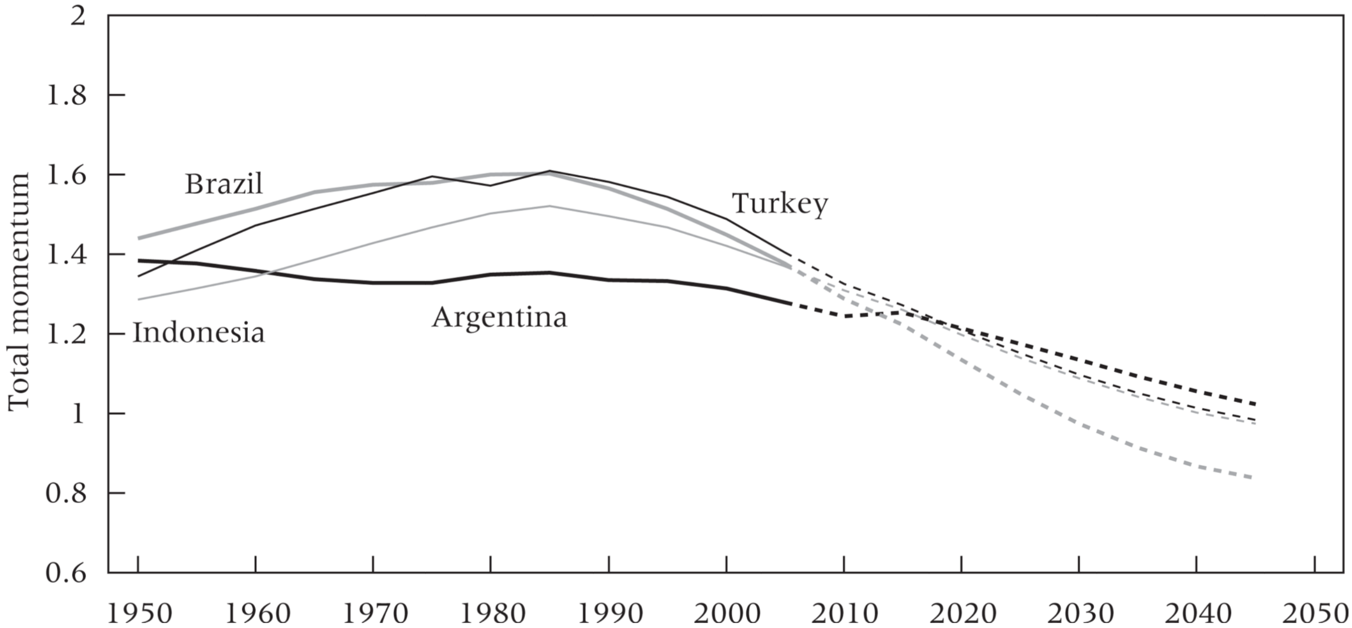

FIGURE 6. Total population momentum in four developing countries, stage 4 of the demographic transition, 1950–2045

NOTE: Dotted lines represent projected trends after 2005–2010.

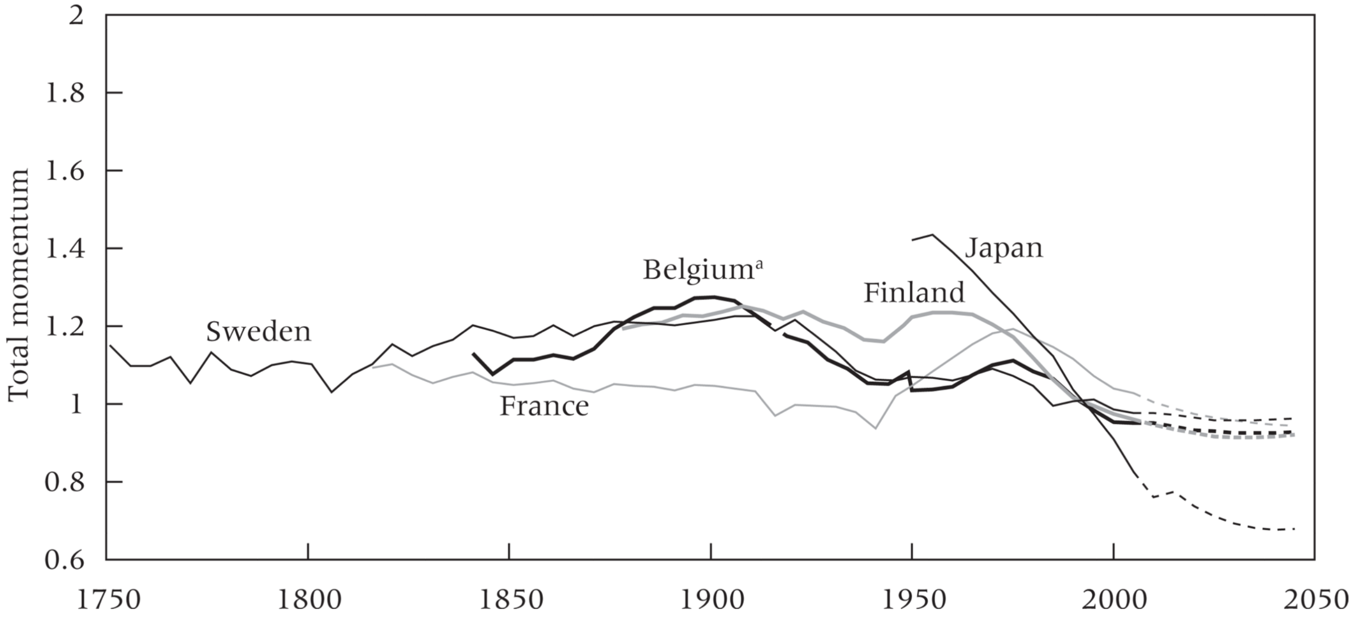

FIGURE 7. Total population momentum in five developed countries, stage 5 of the demographic transition, 1751–2045

NOTE: Dotted lines represent projected trends after 2005–2010.

[a]Data for Belgium missing between 1915 and 1918.

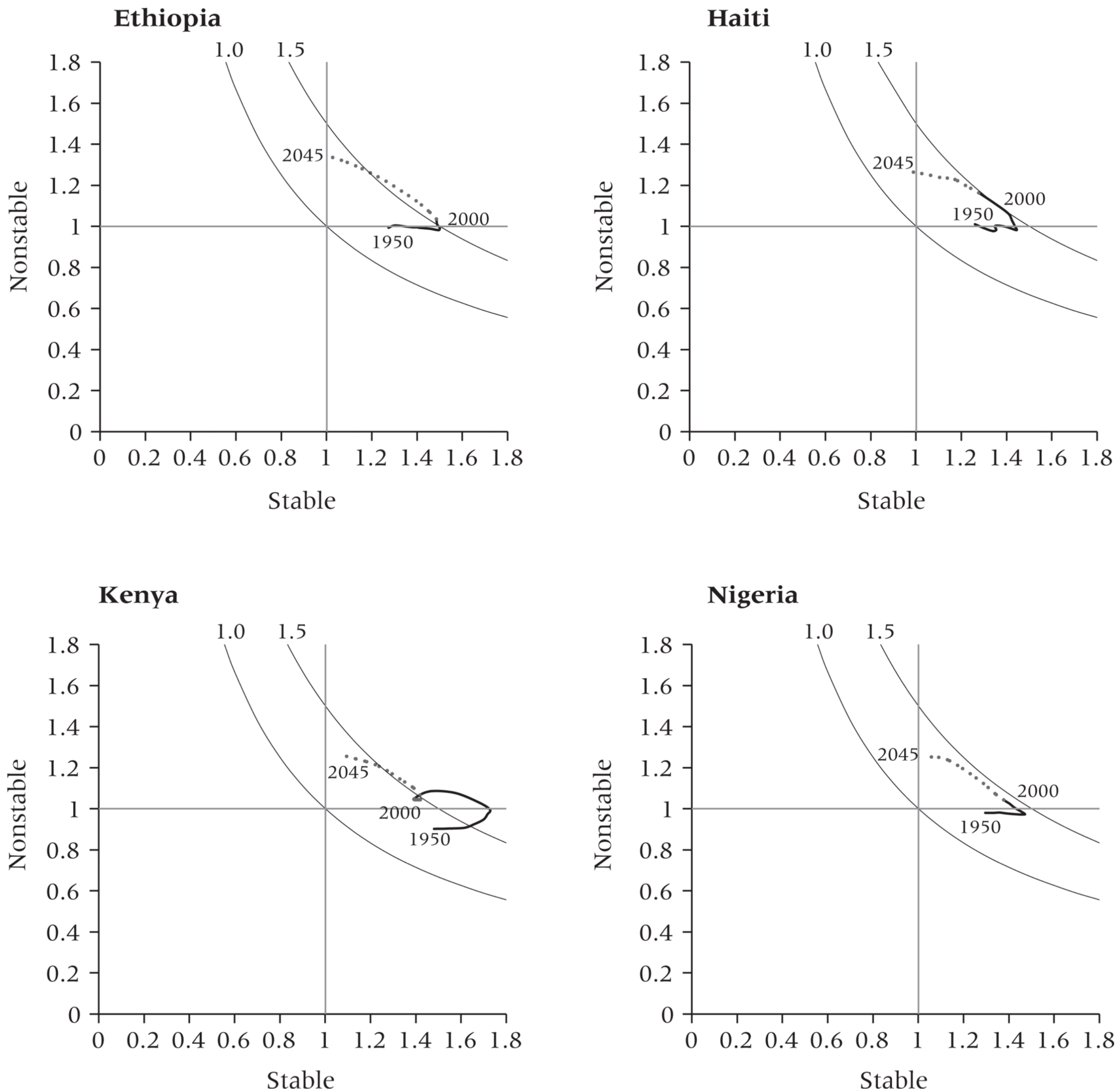

FIGURE 8. Stable and nonstable population momentum in four developing countries, stage 2 of the demographic transition, 1950–2045

NOTE: Dotted lines represent projected trends after 2005–2010. The hyperbolic curves correspond to total momentum values of 1.0 and 1.5.

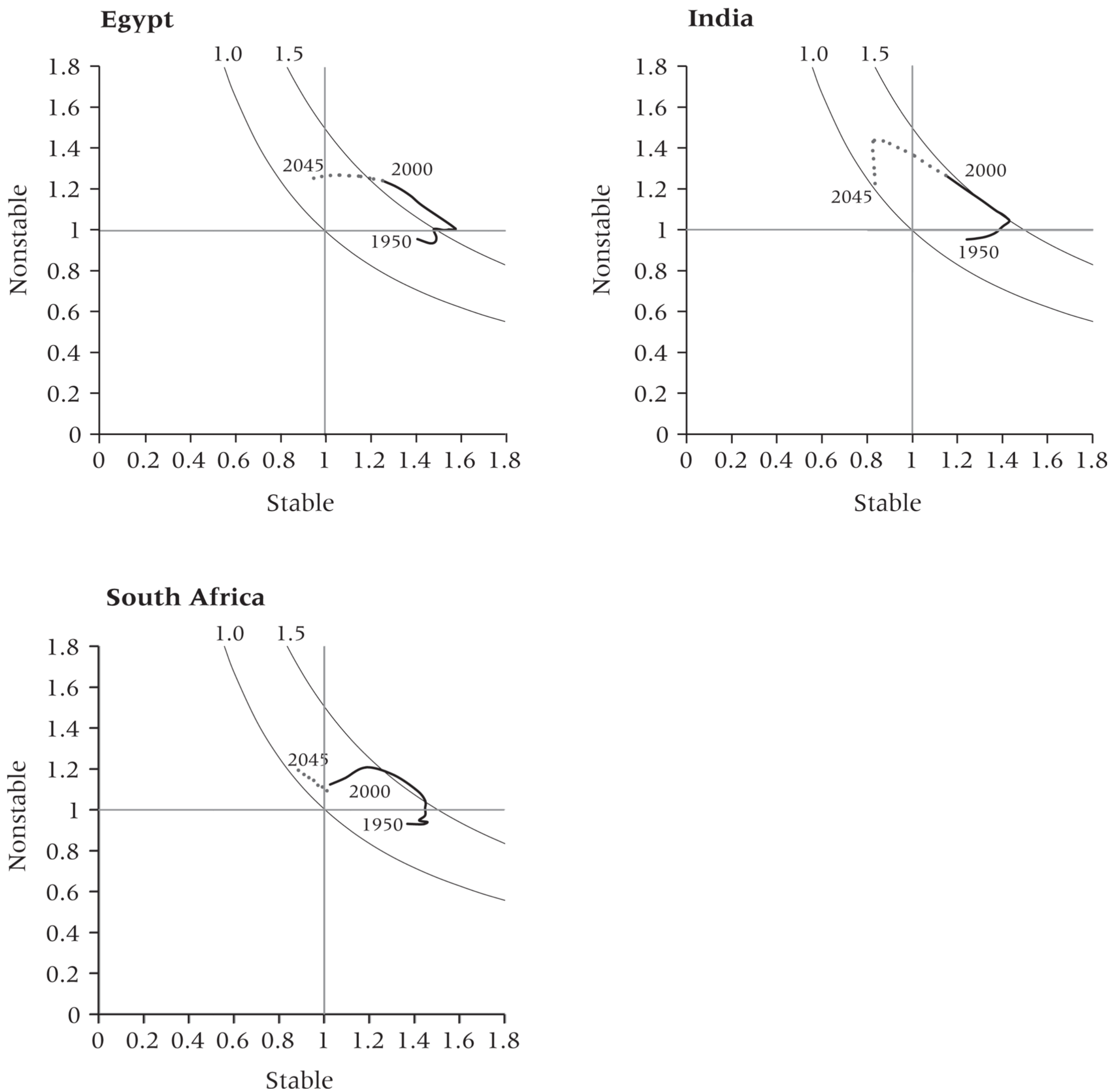

FIGURE 9. Stable and nonstable population momentum in three developing countries, stage 3 of the demographic transition, 1950–2045

NOTE: Dotted lines represent projected trends after 2005–2010. The hyperbolic curves correspond to total momentum values of 1.0 and 1.5.

NIH-PA Author Manuscript

NIH-PA Author Manuscript

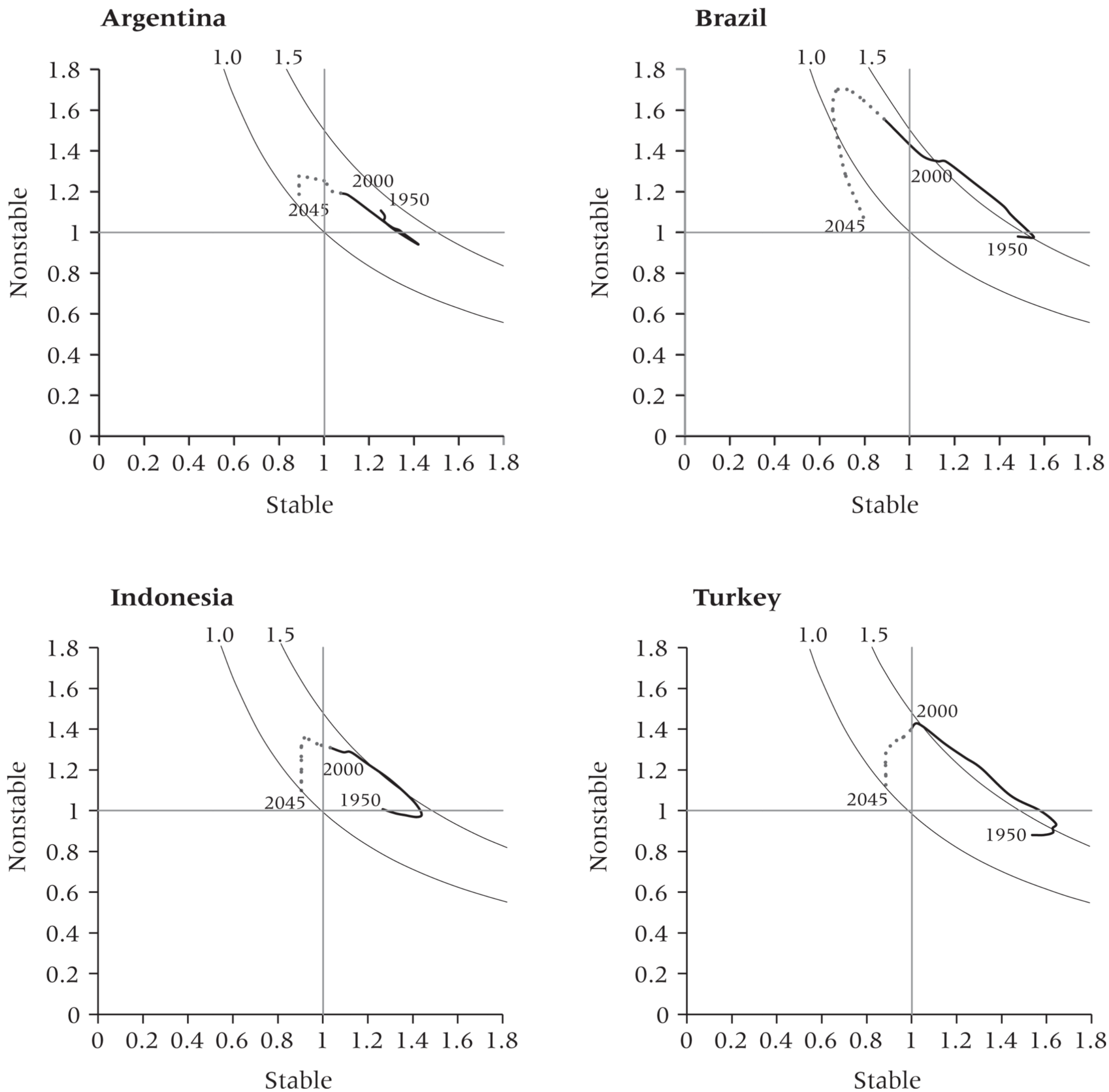

FIGURE 10. Stable and nonstable population momentum in four developing countries, stage 4 of the demographic transition, 1950–2045

NOTE: Dotted lines represent projected trends after 2005–2010. The hyperbolic curves correspond to total momentum values of 1.0 and 1.5.

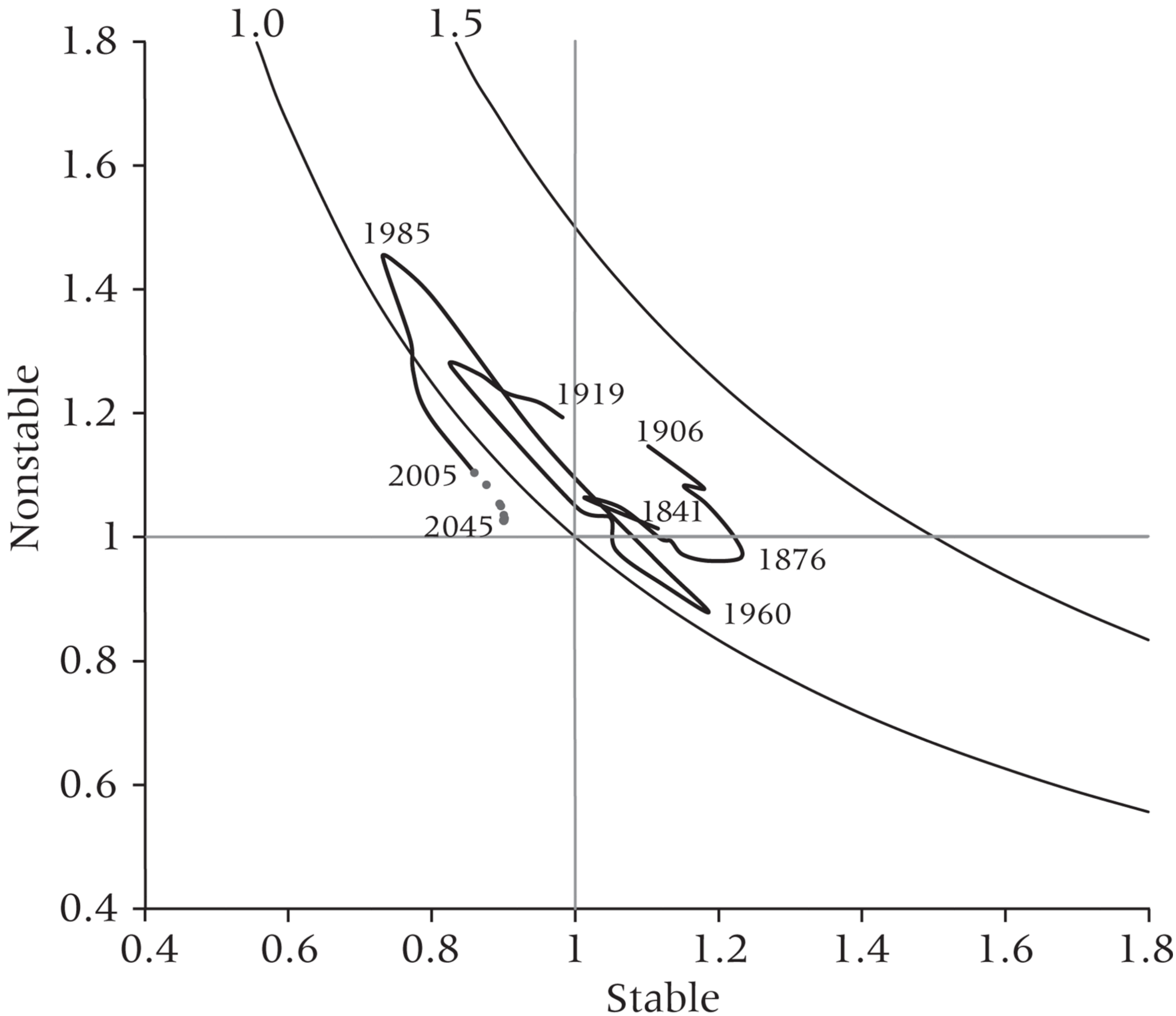

FIGURE 11. Stable and nonstable population momentum in Belgium, stage 5 of the demographic transition, 1841–2045a

NOTE: Dotted lines represent projected trends after 2005–2010. The hyperbolic curves correspond to total momentum values of 1.0 and 1.5.

[a]Data for Belgium missing between 1915 and 1918.

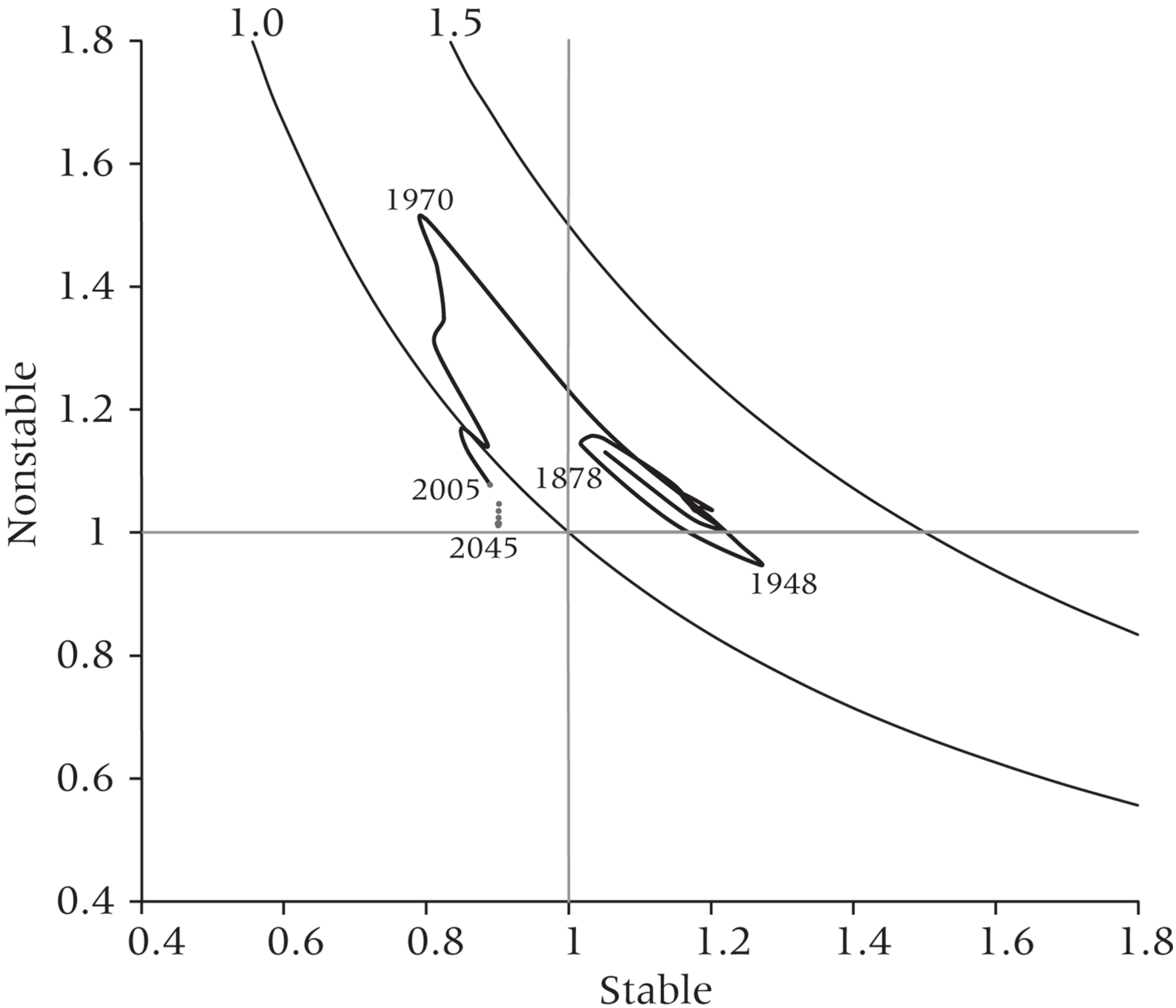

FIGURE 12. Stable and nonstable population momentum in Finland, stage 5 of the demographic transition, 1878–2045

NOTE: Dotted lines represent projected trends after 2005–2010. The hyperbolic curves correspond to total momentum values of 1.0 and 1.5.

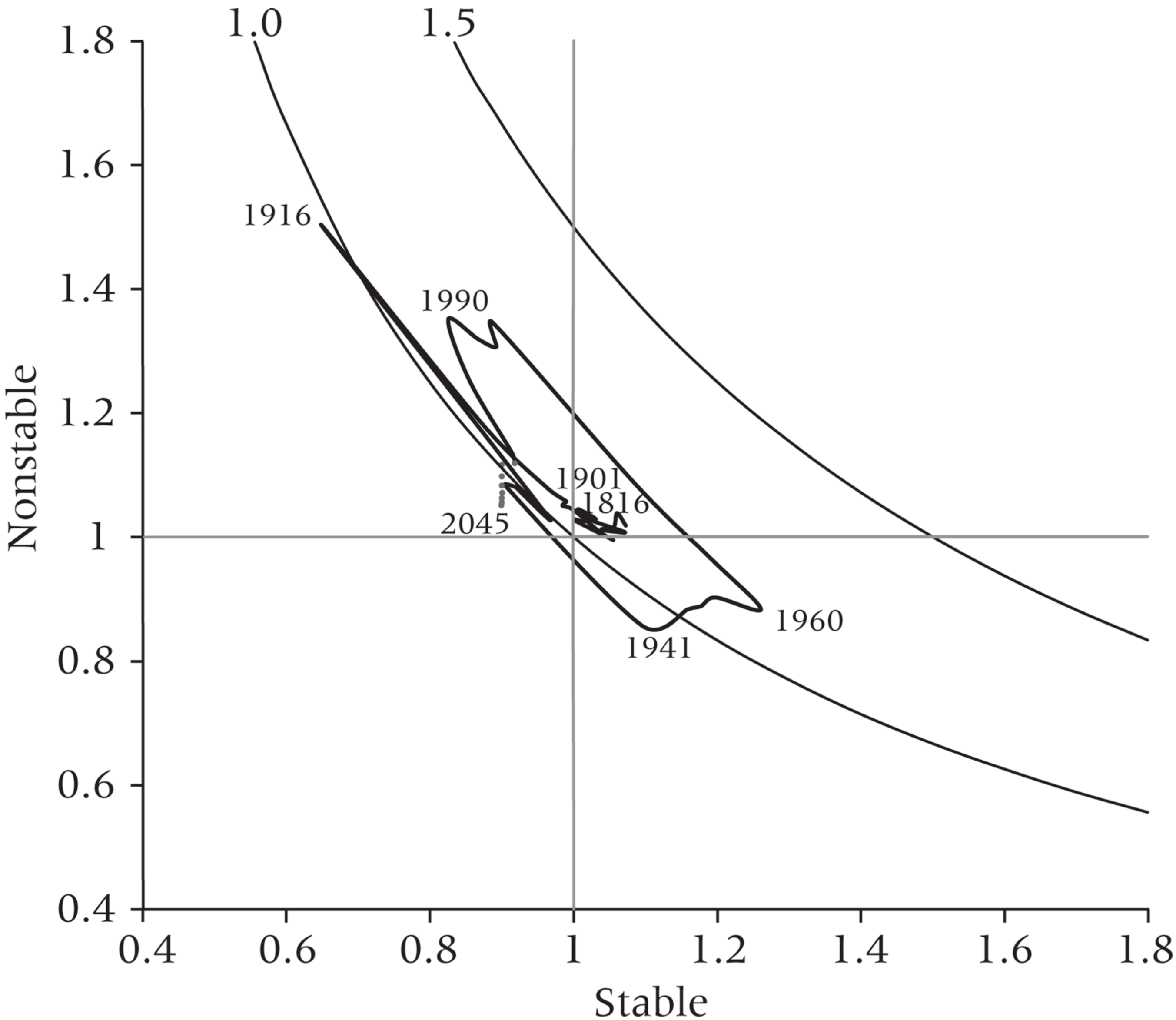

FIGURE 13. Stable and nonstable population momentum in France, stage 5 of the demographic transition, 1816–2045

NOTE: Dotted lines represent projected trends after 2005–2010. The hyperbolic curves correspond to total momentum values of 1.0 and 1.5.

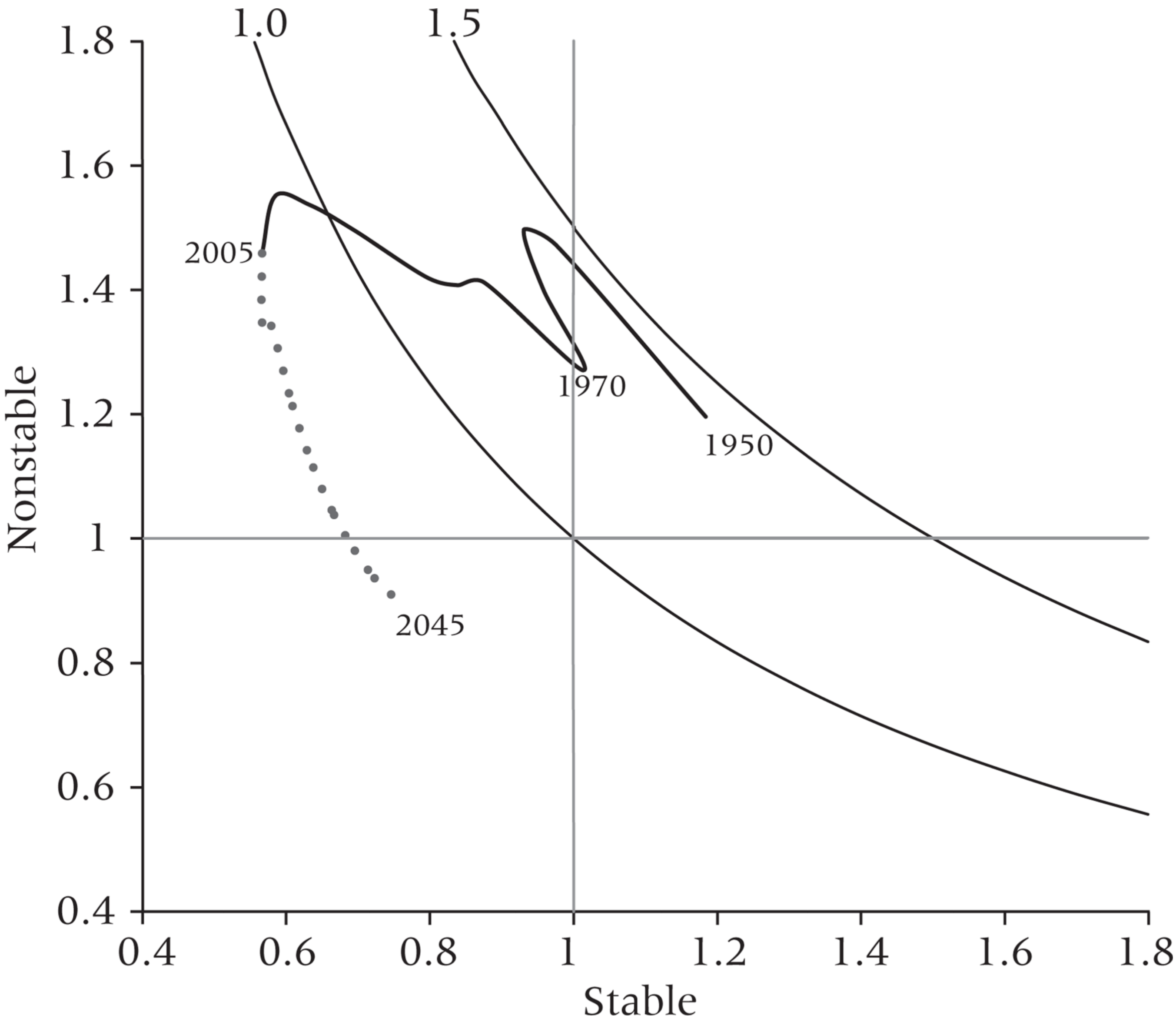

FIGURE 14. Stable and nonstable population momentum in Japan, stage 5 of the demographic transition, 1950–2045

NOTE: Dotted lines represent projected trends after 2005–2010. The hyperbolic curves correspond to total momentum values of 1.0 and 1.5.

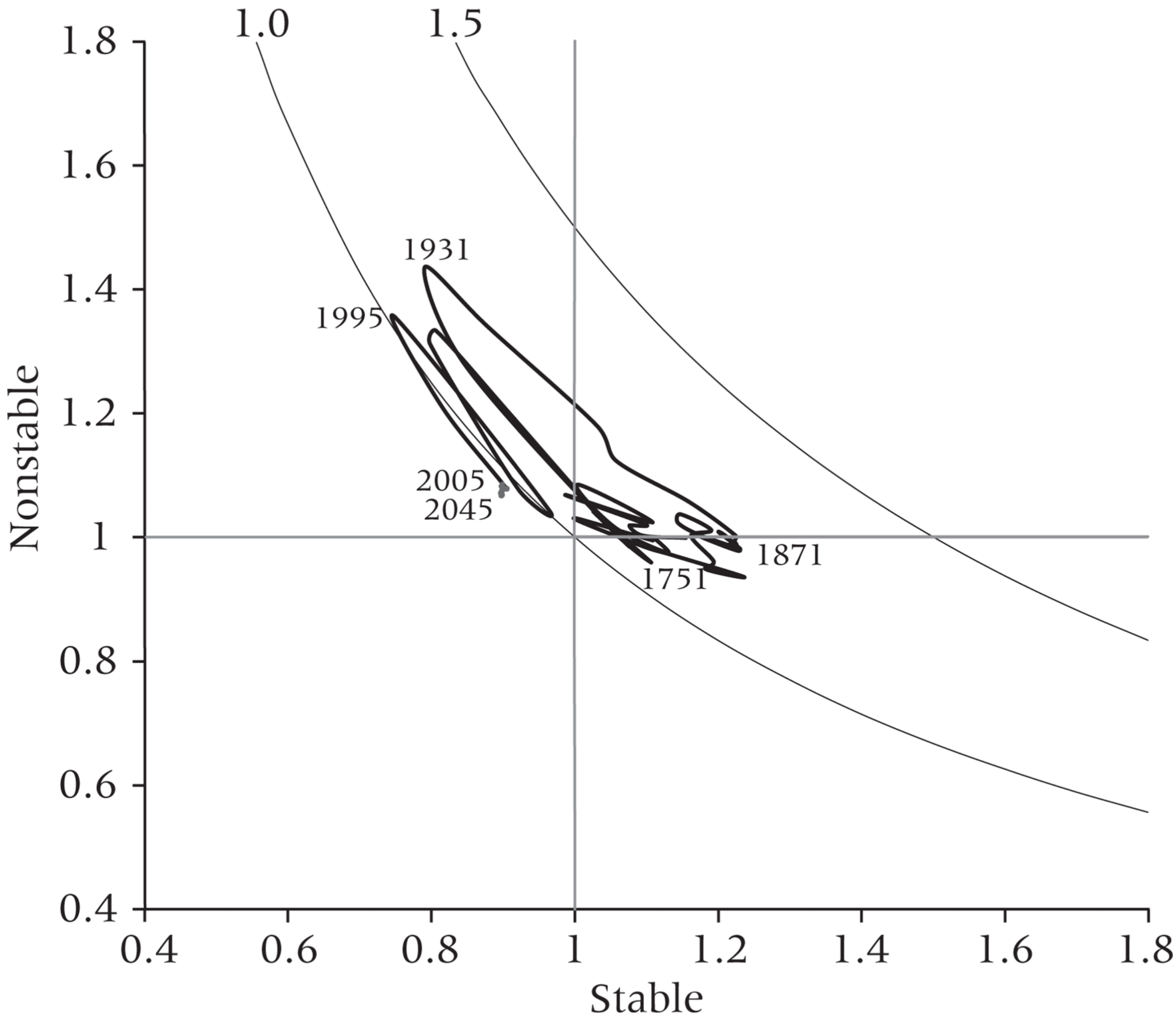

FIGURE 15. Stable and nonstable population momentum in Sweden, stage 5 of the demographic transition, 1751–2045

NOTE: Dotted lines represent projected trends after 2005–2010. The hyperbolic curves correspond to total momentum values of 1.0 and 1.5.

NIH-PA Author Manuscript

NIH-PA Author Manuscript

TABLE 1

Sixteen populations, by stage of demographic transition, with demographic indicators

Stage of transition[a]	Country	Time interval	GRR[b] (2005–2010)	Replacement GRR[c] (2005–2010)	NRR (2005–2010)
2	Ethiopia	1950–2045	2.651	1.262	2.101
	Haiti	1950–2045	1.729	1.154	1.499
	Kenya	1950–2045	2.443	1.250	1.955
	Nigeria	1950–2045	2.354	1.421	1.839
3	Egypt	1950–2045	1.408	1.054	1.336
	India	1950–2045	1.328	1.133	1.172
	South Africa	1950–2045	1.256	1.211	1.037
4	Argentina	1950–2045	1.105	1.026	1.080
	Brazil	1950–2045	0.927	1.044	0.892
	Indonesia	1950–2045	1.066	1.043	1.022
	Turkey	1950–2045	1.040	1.043	1.003
5	Belgium	1841–2045[d]	0.863	1.009	0.856
	Finland	1878–2045	0.892	1.007	0.884
	France	1816–2045	0.912	1.010	0.914
	Japan	1950–2045	0.615	1.007	0.611
	Sweden	1751–2045	0.917	1.008	0.898

[a] See Figure 1.

[b] GRR calculated as TFR / (1 + sex ratio at birth).

[c] Replacement GRR calculated as GRR / NRR.

[d] Data for Belgium missing between 1915 and 1918.

DATA SOURCE: For GRR (gross reproduction rate) and NRR (net reproduction rate): United Nations (2009b).