# BIRTH REPLACEMENT RATIOS: NEW MEASURES OF PERIOD POPULATION REPLACEMENT

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## ABSTRACT

In this article a new set of measures of period replacement is proposed that complements the Total Fertility Rate and improves on the Net Replacement Ratio. While the TFR can be seen as the ratio of births to period mean size of the mothers' generation, the Birth Replacement Ratio is the ratio of births to the size of the mothers' generation at birth. In this way, the TFR differs from the BRR due to mortality of the mothers, but also to emigration and immigration. The contribution of each of these factors can be quantified by means of a decomposition technique. In contrast to the NRR and alternative replacement indicators, the BRR is not a synthetic-cohort measure: it refers to the actual number of births and the depletion of the current cohorts of mothers. In stable populations, however, the Net BRR is virtually undistinguishable from the NRR.

The application of the BRR to a number of countries shows how important migration is as an element in birth replacement. Countries with high emigration, like Morocco may not be reproducing themselves due to this factors, while inmigration makes an important contribution to replacement in receiving countries like Spain, the U.S. or Switzerland.

## INTRODUCTION

Demographers generally insist in the difference between fertility and reproduction, generally represented by indicators like the *Total Fertility Rate* (TFR) or the *Net Reproduction Ratio* (NRR). While fertility only looks at childbearing behaviour, reproduction or replacement measures try to look at fertility and mortality combined to determine potential population growth (Sardon, 1991; Espenshade, Guzmán and Westoff, 2003; Kohler and Ortega, 2003). But the NRR has important shortcomings as a measure of population reproduction:

a) The NRR does not refer to any real population: Its synthetic cohort character means that it does not indicate natural growth at any moment in time but rather potential growth only if mortality and fertility rates remain constant over a generation, an unlikely scenario.
b) It does not reflect all the components of population growth: only natural growth. In doing so it neglects the impact of migration on population growth: emigration leads to population decrease while immigration leads to population increase.

When the indicators are just interpreted as summary measures of the complete fertility and mortality schedule with a pure period interpretation, these shortcomings are of little importance, but very often this is not the case.

There have been some attempts in the past to reduce the impact of this shortcomings:

(a) Reproduction Ratios at different ages have been proposed by Sardon (1991),
(b) Reproduction Ratios under different net migration scenarios have been also proposed by Ryder (1997), Calot and Sardon (2001) and Smallwood and Chamberlain (2005),

But none of these proposed indicators solve the problems mentioned: The first solution provides indicators which have an even more complex interpretation, and which still do not refer to real population growth. The second, is also affected by the synthetic cohort nature of the calculations, and also makes interpretation more difficult: the pure period interpretation is lost, since we are making scenarios about future migration flows, and their role as an indicator of potential growth is also lost since we can obtain any NRR value by assuming a proper migration scenario. This means that the indicator is not a measure of potential growth, but rather a tool for assessing the sensitivity of future population growth to different migration scenarios. It is an imperfect tool at that: if that is the purpose, it is better to make a complete population projection, which does not require more information and refers to real populations.

In this paper we introduce a new replacement indicator, the *Birth Replacement Ratio* (BRR), which circumvents these shortcomings:

(a) It is a period indicator whose meaning refers to a real population: it measures whether current births are replacing the number of women born in the mother's generation. As such, it is not a measure of potential growth, but of growth today.

(b) It is an indicator that takes into account all the dimensions of population change:

- Higher fertility means a higher number of births and a higher BRR,
- Cohort mortality of the current mother's cohort has lead to a depletion of the current mother's generation leading to lower BRRs,
- Lifetime emigration of women from the current cohorts of mothers also leads to a depletion of the mother's generation and a lower BRRs,

- Immigrant women contribute to the overall number of births. Their contribution is the result of two components: their fertility level, and their number.

The first property means our indicator is easier to calculate than the NRR because information on mortality is not necessary: only births in the past, and the information already available to calculate the TFR: age-specific fertility rates.

The second property is important because it makes it possible to decompose the current BRR as the result of the contribution of each of these factors to the current BRR.

The BRR indicator provides an important addition to the demographer´s toolkit since migration is becoming the main component of population growth in many countries and it is not explicitly considered in current reproduction indicators. It also brings attention to the important role that emigration has had in diminishing population growth in some sending countries, and to its reverse role in increasing the number of births in receiving countries.

In the following section we will provide a definition of the BRR which arises as a natural extension to population replacement of the TFR. Next, some applications will be presented. Then, we provide a decomposition of the BRR in its constituent factors (fertility, mortality, emigration and immigration) and an application of the decomposition method.

## THE BIRTH REPLACEMENT RATIO (BRR)

### Definition

The TFR is the most widely used indicator of period fertility. Its limitations are known, in particular it is affected by tempo distortions and therefore cannot be used as a measure of current period fertility (Bongaarts and Feeney, 1998; Kohler and Ortega, 2004). Probably, the most persuasive argument for its use stems from Calot (2001): the TFR may be seen as a period replacement index. It puts in comparison the current number of births with the mean size of the mothers' generation (Calot, 1984). Let us recall that the TFR is defined as:

$$TFR(t) = \sum F_x(t)$$

where $F_x(t)$ represents the age-specific fertility rate for age x in year t. It is calculated as the ratio between the number of births born to women age x, $B_x(t)$ and exposure to these women in the period, $E_x(t)$. The mean size of the mother's generation is therefore defined as:

[1]

$$G_t = B_t / TFR_t = \sum [ F_x(t) / TFR(t) ] \cdot E_x(t)$$

Where it can be seen how $G_t$ is a weighted average of population exposures, with the weights proportional to the fertility rate. It is therefore roughly a measure of the size of the generation of mothers.

Under this perspective, Calot proposes the TFR as an indicator of period replacement. As such, it presents an undesirable feature: a measure of replacement should compare similar population concepts. This is not the case here: we are comparing births to a weighted average of period population. A real measure of replacement would compare births to births. That is the role of our proposed indicator, the *Birth Replacement Ratio* (BRR). The idea is to calculate a mother's generation size at birth, $BG_t$, calculated as a weighted average of female births in the past:

[2]

$$BG_t = \sum [ F_x(t) / TFR(t) ] \cdot B^f(t-x)$$

where $B^f(t-x)$ is the number of female births in period t-x. The BRR is therefore defined as:

[3]

$$BRR_t = B_t / BG_t$$

The $BRR_t$ has a similar interpretation to the Net Reproduction Ratio, $NRR_t$ as a ratio of births to births. The difference lies in the pure period interpretation of the $BRR_t$, which refers to the present number of births in relation to the number of births in the past. In contrast, the $NRR_t$ corresponds to the ratio between quantities in the synthetic cohort fertility table: it compares the number of births in the fertility table to the radix. Note also that, the way we defined the $BRR_t$, we include both male and female births. This makes it easier to compare it to the $TFR_t$. If one wants to compare female to female births, a *Net Birth Replacement Ratio* can be calculated as:

[4]

$$NBRR_t = B^f_t / BG_t$$

where $B^f_t$ corresponds to the number of female births in period t[1]. Note, that under stable population conditions in a closed population, the NBRR and the NRR would be almost undistinguishable (see Appendix). The differences therefore can be seen in the way that the indicators deal with departures from the stable population framework. The NRR, despite the presence of instability, provides a closed-population stable-population indicator, which has a prospective nature conditional on stability. The NBRR, assumes as natural that population rates are not stable and populations are open, and it tries to incorporate that experience to the measurement of population reproduction.

**Applications**

The $BRR_t$ is very simple to calculate. In addition to the age-specific fertility rates, $F_x(t)$, only the number of female births in the past is needed. These measures are readily available for many countries. As an example, we will compute the new replacement ratios for a number of countries around 2000 using only data available from the UN web sites (World Fertility Report, 2003; World Population Prospects: The 2004 Revision Population Database, 2005). Since the UN provides only age-specific rates for five year age-groups, $BG_t$ needs to be calculated accordingly as:

$$BG_t = \sum [\ {}_5F_x(t) / TFR(t)\ ] \cdot 5 \cdot 0.4886 \cdot AB(t\text{-}x\text{-}5;t\text{-}x)$$

[1] Note that, similar to the TFR and the NRR, the BRR and the NBRR can also be defined for males. Also, if the sex classification of births is not available a standard sex ratio at birth can be used (i.e: 0,4886).

where AB(t-x-5;t-x) corresponds to the average number of births per year in the five year period [t–x–5,t–x]. These are available online from the World Population Prospects database, but only for five year periods starting in 0 or 5. Since only the total number of births is available, we apply a standard sex ratio at birth of 0.4886 to obtain the number of female births.

In table 1 the BG, BRR and NBRR indexes are calculated for a number of countries from all continents. They can be compared to the TFR and the G indexes. The comparison between the TFR and the BRR is particularly illustrative. In general we can observe two main elements in the difference: migration streams and mortality:

- Those countries receiving large immigration flows tend to have BRRs well over the TFR. This is particularly the case of Australia, where the TFR is 1.75, but the BRR is 2.11, above replacement levels. It is also the case of France (1.79 vs 1.91), Switzerland (1.41 and 1.59) or the US (2.13 and 2.29), and to a minor extent of other European countries like Spain, Italy or the UK where immigration is able to balance the effect of mortality so that birth replacement is very close to the TFR.
- In Sub-Saharan African countries, both high mortality and emigration combined lead to birth replacement well below the TFR. It is the case of Uganda (6.97 and 5.09) and Zambia (5.87 and 4.05).
- Countries experiencing large emigration flows show birth replacement levels well below the TFR. Among these countries we have countries where total fertility is relatively high and BRR is closer to replacement, like the Dominican Republic (2.93 and 2.11), and quite a large group of countries where births are not being replaced, either in contrast with the TFR (Albania, 2.11 and 1.74; Iran,

2.17 and 1.76; Turkey, 2.48 and 1.93), or aggravating below replacement fertility (Belarus, 1.28 and 1.23; Cuba, 1.59 and 1.42; Romania, 1.31 and 1.13).

- China is an exception in this respect. Birth Replacement shows a larger value of birth replacement (1.63 compared to 1.39) which cannot be explained by large immigration. The incorporation of Hong-Kong and Macao can be a factor, but does not explain such a large difference. There could be a problem of congruence in the data that would require further analysis beyond the scope of this paper.

In summary, birth replacement patterns can be at times quite different from TFR patterns. In particular, the largest differences are connected to migration. In general, receiving countries would benefit from immigration that brings births close to replacement levels or even over it. In contrast, in the sending countries birth replacement might not be guaranteed despite a relatively high fertility, or aggravating a low fertility situation. This is a sign of depopulation that should be a matter of public concern.

## DECOMPOSITION OF THE BIRTH REPLACEMENT RATIO AND THE TOTAL FERTILITY RATE

We have seen that empirical differences between the TFR and the BRR can be to a large extent explained by migration and mortality patterns. In this section we will provide an analytic decomposition of the difference between the TFR and the NRR. We will also show how the TFR can be seen as a weighted average of the fertility of different population groups. As a result, immigration has two different effects on birth replacement in the receiving regions:

- Differential fertility of natives and immigrants has an effect on the TFR. This will generally be a second order effect,
- The contribution of immigrants to the size of the mother's generation makes birth replacement higher than total fertility.

After providing the analytical decomposition formulae, we will show an application to Spanish birth replacement from 1996 to 2004. This is a particularly interesting case due to the very fast immigration received in the recent years.

## From Total Fertility to Birth Replacement

As we have seen in the previous section, the differences between the TFR and the BRR arise because of differences between the period's mother's generation size and mother's generation size at birth. These differences arise from depletion of the native mother's generation size at birth, and by immigration of non-native women. In that way, the period's mothers generation size can be partitioned as:

$$G_t = G^{Nat}_t + G^{For}_t \qquad [5]$$

Where $G^{Nat}_t$ is the native mother's generation at time t and $G^{For}_t$ the size of the mother's generation born abroad. Each are defined as weighted averages of the women's population classified by place of birth similar to equation [1] :

$$G^i_t = \Sigma[F_x(t)/ISF_t] \,.\, E^i_x(t) \,, \;\; i \in \{Nat, For\} \qquad [6]$$

Note also that, if desired, both the native and the foreign born could be classified according to more dimensions like race, country of birth, etc. We can also define the proportion of the mother's generation by place of birth:

[7]

$$P^i_t = G^i_t / G_t$$

From our perspective, the conceptual difference between the native-born and the foreign-born is that the native population present at time t originates from $BG_t$, whereas the foreign-born does not. The difference between $BG_t$ and $G^{Nat}_t$ is the result of mortality and emigration. Since the mortality of the potential mother's is concentrated in the first year of birth and childhood, we can assume that mortality comes before migration. We therefore define the mean generation size that would have been observed in year t in the absence of migration as:

[8]

$$G^{Surv}_t = \sum 0.5[\, L_x(t-x) + L_{x+1}(t-x)]B^f(t-x)$$

Where $L_x(t-x)$ is the female cohort life table person-years-lived at age x of the cohort born in year t–x. The difference between $G^{Surv}_t$ and $BG_t$ can then be summarized by a multiplicative factor that represents average survival of the cohorts of mothers:

[9]

$$\bar{\lambda}_t = G^{Surv}_t \;/ BG_t$$

finally the difference between $G^{Surv}_t$ and $G^{Nat}_t$ results from emigration of native women. We can define an emigration factor that corresponds to the proportion of mother's that would have been observed in year t and are missing because of emigration:

[10]

$$k^{Emig}_t = 1 - [G^{Nat}_t / G^{Surv}_t]$$

Inserting equations [9] and [10] into equation [5] results into the following partition of $G_t$:

[11]

$$G_t = BG_t \cdot \overline{\lambda}_t \cdot (1-k^{Emig}_t) + G^{For}_t$$

We can finally solve equation [11] for $BG_t$ and insert into equation [3] to obtain a decomposition of the birth replacement ratio in its components, fertility summarized by the $TFR_t$, survival to motherhood, summarized by $\overline{\lambda}_t$, lifetime emigration of native born women, $k^{Emig}_t$, and $P^{For}_t$, the proportion of foreign born in the mean mothers' generation size.

[12]

$$BRR_t = TFR_t \frac{\overline{\lambda}_t \cdot (1 - k_t^{Emig})}{(1 - P_t^{For})}$$

In case where there is information regarding mortality, at least approximate, but not regarding nativity, it is also possible to compute a net migration factor, $k^{NetMigr}_t$, which would be equal to:

[13]

$$k_t^{NetMigr} = \frac{1 - k_t^{Emig}}{1 - P_t^{For}} - 1$$

Inserting this definition in equation [12] we arrive at the alternative decomposition:

[14]

$$BRR_t = TFR_t \cdot \overline{\lambda}_t \cdot k_t^{NetMigr}$$

**Decomposition of the Total Fertility Rate**

While equation [12] provides the connection between the BRR and the TFR, the effect of immigration of birth replacement is not limited to that. If there are fertility differentials between the native-born and the foreign-born – or any other population subgroups - the TFR is a weighted average of the fertility of the different groups. For each population subgroup, i, a fertility index can be defined as:

[13]

$$F^i_t = B^i_t / G^i_t$$

So that, inserting into any partition of $G_t$ in population subgroups as that given by equations [5] and [7] results into:

[14]

$$TFR_t = \sum P^i_t \cdot F^i_t$$

Due to the quasi-additivity of the TFR (Calot, 1984), the group's fertility index is very similar to the group-specific total fertility rate, $TFR^i_t$. The differences between them are connected to the difference in the timing of fertility of the different subgroups. An advantage of $F^i_t$ as an index is that it can be obtained directly from equation [13] without information regarding the number of births classified by age and mother's place of birth.

## Application to Spain

In this section we will apply the decomposition techniques of the BRR and the TFR to the evolution of fertility between 1996 and 2004. This is a particularly interesting application due to the very large immigration flow that has arrived to the country during the period. If we only estimate the impact of immigration on the TFR, it would seem that the effect is quite reduced. The BRR, on the contrary, captures the large increase in the proportion of foreign-born potential mothers in the population. There is only one caveat: whereas the women's population is classified both according to place of birth and nationality, the number of births is only classified according nationality of the mother. As a result we would use two different partitions: the BRR is partitioned according to the mother's place of birth using equation [12], whereas the TFR is decomposed according to the mother's nationality.

The decomposition of the BRR is shown in table 2 for the years 1996 to 2004. Only data publicly available in internet has been used for the calculations. Some notes regarding the calculation of the different quantities involved in the calculation:

- $E_x(t)$: Exposure has been estimated for single year birth cohorts based on the continuous registration system that started in 1996. For 1996 the available figures refer to May 1st, and the population figures have been used as exposures. For years 1998 to 2004 figures refer to Jan 1st, and exposure has been calculated as the half-sum of the population at the beginning and end of the year.
- $E^i_x(t)$ , $i \in \{Nat, For\}$: Classification by nativity is only available by five-year age-groups. We have used the average at the beginning and end of the period.

- ${}_nF_x(t)$: Fertility rates have been calculated for single cohorts in order to obtain the weights necessary to calculate G and BG. In order to partition G by nativity, fertility rates for five-year age-groups have also been calculated. Data is available until year 2003. Note that the TFR calculated based on our fertility rates is slightly different from the official TFR published by the INE. Since they do not give details as to the procedure they use, we cannot assess the reasons for the difference, but they must come from the way of calculating exposure.
- G and BG: The figures have been calculated using the $F_x(t)$ as weights. For 1997, G and BG have been calculated by linear interpolation. As shown in Calot(1984), and confirmed by looking at the rest of years, the evolution of G is very smooth and the error incurred is very reduced. For 2004, where the tabulation of births by age of the mother is not yet available, calculation of G and BG has been based on using the same fertility schedule as the one observed in 2003.
- $G^{Nat}$ and $G^{For}$: The partition has been based on the available information by five-year age-groups. Since the results do not add up to G, they have been multiplied by the necessary factor (ranging from 1.003 to 1.007).
- $G^{Surv}$: The female cohort life tables have been constructed based on data in the Human Mortality Database (2005). In particular, lexis triangle deaths have been combined to obtain age-cohort estimates of $q_x$ and $a_x$ for single years of age. We have then applied equation [8].

The results in table 2 show a slight recuperation of the TFR from minimum values of 1.15 in 1996 and 1998 to levels close to almost 1.3 in 2004. This means an increase of over 10% in six years. This increase is partly the result of the higher fertility of immigrants, as we will soon see, but the main impact of inmigration does not effect the TFR but the BRR: birth replacement has increased from 1.12 to 1.47 (more than 30%) between 1996 and 2004. The main reason is the extremely fast inmigration process that has led foreign-born women to represent 11.5% of the potential mother's generation in 2004 when they only represented a 2.5% in 1998. This has had a very large impact on the number of births and net birth replacement is now at 0.7 (which means a 30% population decrease over a generation) instead of 0.5: a halving of the population every generation. Of course, this has gone together with record figures of population increase as well, but that is beyond the scope of this paper.

One unexpected finding in table 2 refers to the emigration factor, $k^{Emig}$, which was very close to zero in 1996, indicating that less than one percent of the potential mothers alive in 1996 were abroad. From that year onwards, the index gets smaller every year and in 2004 is –0,041, a relatively large proportion. This means that there are more native-born women present than those that would have been expected to survive according to observed cohort mortality and assuming no migration. In the case of 2004, there are even more women born in Spain alive in 2004 than they were born!. That is obviously impossible. While, in theory, it would be possible to observe negative $k^{Emig}$ under very specific circumstances of interference of migration and mortality (i.e: a large fraction of children migrating in the first years of live, so that their deaths are not recorded, and who come back to Spain at a later moment in time), this does not seem to be the case: emigration was high in Spain until the 1970s, but it affected older generations. Since 1980 emigration has been very low (Anuario de Migraciones, 2002). For this reason, a figure such as that observed in 1996 should not be far from the true value: less than one percent migration. There are several competing explanations of this fact: underestimation of births, an overestimate of cohort mortality, duplicate registers of native born, and foreign born registered in the *Padrón* as native born. The two first explanations are not likely: birth registration is regarded as complete (Reher and Valero, 1995), mortality levels seem to be in agreement with current knowledge. Double registration would seem to be a possibility, although the *padrón* has built in mechanisms in the period analyzed by which registration in a certain *municipio* must be balanced automatically by a withdrawal from the previous one (Spanish *Real Decreto* 2612/1996). In principle, the law also requires identification to show that the registration data are true, although the law is ambiguous:

> "the municipal hall might confirm the truthfulness of the declaration consigned by the inhabitants by requiring them to display their National Identity Card or Residence Card, Family Book, documents proving occupation of their home, or analogous documents" (Article 59.2, *Real Decreto* 2612/1996)

It seems the case that not every municipal hall is equally thorough at checking the accuracy of the data. In table 3 we show the number of persons from the same Spanish birth cohorts registered in 1998 and 2003 together with the number of births registered for those cohorts. It shows how the absolute number increased in all cases, in some instances as much as by two percent. Note that, in the absence of a large pool of emigrants, one would have expected the numbers to decrease due to mortality. Note also how already in 1998 the registered figures for the 1984-1988 and 1979-1983 cohorts were above the registered number of births by as much as 7.5% for the latter cohort. Since it is quite unlikely that the number of births registered is underestimated, this indicates two problems: there was already over registration in 1998, and the problem became even worse so during the five-year period when massive immigration began. The first problem must be connected to double registration of some sort, whereas the second might also be connected with the existence of some incentive for people to declare being Spanish born if this was not thoroughly checked[2]. This leads to a parallel trend in $k^{Emig}$, which becomes negative meaning that there are more people registered than expected to be alive, and the foreign born registered which grows from 2 to 11 percent. Under this circumstances it might be more realistic to interpret the net migration factor as a lower bound of immigration rather than the emigration and the foreign-born proportion separately. The net migration factor has grown to levels close to 18 percent in 2004.

While the high proportion of recent immigrants have pushed birth replacement upwards, it might have also had an effect on the TFR. Equation [14] shows that the impact on overall fertility would depend on the proportion of foreign born and the level of differential fertility. Unfortunately, civil registration does not provide information about the place of birth of the mother, but it does record the nationality of the mother. We can therefore partition fertility according to nationality. To a large extent both coincide. The two main differences regard naturalization, and foreigners with third country nationality[3].

[2] It would always have been possible to check, since the Spanish system is based on civil registration, and birth certificates are commonly asked as proof of birth.

[3] Naturalization requires, in general, ten years of residence except for Latin American nationals for whom it only requires two years, and for people married to a Spanish National where only one year is required (Anuario de Migraciones, 2002: 507). The total number of naturalizations has been increasing over the years as the migrant stock increased from numbers around 10 thousand in 1997 to levels around 25000 in 2003 (Anuario Estadístico de Extranjería, 1999, 2003), more than half of those being formerly Latin American citizens. Third country nationals explain why there are about 500 more women in G with Italian citizenship than italian-born, whereas, in contrast, there are 300 more women in G born in Argentina than with Argentinean citizenship.

In table 4 we can observe how fertility of foreign nationals has been consistently above that of Spanish nationals, but the differential has narrowed: until 1999 fertility for foreigners was above two children per woman, with levels below 1.2 for Spanish citizens. In 2004 the differential is only 1.25 to 1.56. This decline in the average fertility of foreigners is connected with two different processes: on one hand, fertility has declined for all groups of foreigners. Declines have been particularly intense for American nationals (1.82 in 1999 and 1.30 in 2004) and European nationals (1.50 in 1999 and 1.22 in 2004, below Spanish nationals). On the other hand, the composition of the inmigrant stock has changed dramatically. The proportion of Europeans and Africans has declined with a big increase in the proportion of Americans, having lower fertility. We note some nationalities that have particularly increased, Romania, Ecuador and Colombia. All three nationalities are characterized by very low fertility, in the case of Colombia lower than Spanish nationals since 2003. Among the main national groups, only Moroccans have high fertility levels, above three, higher than fertility in Morocco.

Note that the fertility index F is not exactly equal to the TFR, although it would be very similar if there are no large differences in timing (Calot, 1984). In the case of Spain there are some differentials but they are not very large. Mean age at childbearing, for instance, ranged in 2001 between 25 for Romanian mothers to 32 years for German mothers (Anuario Estadístico de Extranjería, 2003). F has two advantages over the TFR: its role in the exact decomposition of the overall TFR and its information requirements: the age distribution of foreign births, not always readily available, is not needed.

The last rows of table 4 show a reconstruction of fertility of Spanish born women based on imputed fertility for non-Spanish born nationals equal to the average of the fertility of the Spanish nationals and the nationals from the continent of birth. The results suggest that fertility of Spanish born women has not increased since 1997 and is still at levels around 1.10 children per woman. In terms of the birth replacement decomposition, this would mean that all the registered increase in replacement ratios is connected to the recent inmigration wave. One part of the effect has been to increase the mean fertility level from levels around 1.15 to levels around 1.30, the second has been to increase the mean size of the mother's generation by 17% in 2004. The prospects however indicate that fertility differentials are going down and that in the future the second effect will probably be dominant.

**DISCUSSION**

We have seen that the Birth Replacement Ratio provides a very interesting alternative to former replacement indicators like the NRR, and a most useful companion to the most commonly used TFR, particularly in contexts where migration plays an important role: fertility indicators like the TFR refer to the eventual replacement of the current generation of mothers, but they loose sight of the relative size of the current generation of mothers. In contexts of high emigration, even relatively high levels of fertility might not guarantee replacement, like we have seen in Morocco. Conversely, inmigration might contribute to a large extent to birth replacement like we have seen in Spain, Switzerland or Australia. The contribution of migration to birth replacement is today of much greater impact than mortality, particularly in low mortality countries. For this reason the BRR is more informative than the NRR.

A second advantage of the BRR over alternative reproduction indexes like the NRR is that it requires information that is readily available: basically only time series of births and age-specific fertility rates. This allows the computation for a large number of countries and periods. If more information is available regarding mortality and the distribution of the population by country of birth, it is also possible to separate the effects of fertility, mortality, inmigration and emigration (or net migration). There might also be surprises connected to this: in Spain we have found previously unnoticed limitations of the source (the *padrón*) by which the information regarding place of birth should be treated with caution.

There are a number of extensions that have not been covered in this paper but come out naturally from the analysis:

- Regarding computation, it is possible to provide simplified formulae for the mean survival factor in the spirit of Sardon (1991).
- Regarding the level of analysis, it is possible to apply BRRs to the analysis of replacement at other aggregation levels: provinces, towns and villages are very heterogeneous regarding migration trends in most countries. The BRRs can highlight this by separating the effects of inmigration and emigration.
- Regarding the replacement unit, one does not need to limit the analysis to birth replacement or to the male sex. Similarly to extensions of the NRR, it is possible to compute replacement indexes at different ages distinguishing the effect of migration and mortality of the mothers generation and of the children generation.

- Regarding the literature on tempo distortions in the TFR, the decomposition we provide is perfectly compatible with tempo-adjustment, but answers a different question: tempo adjustment provides answers to questions like what would have been fertility levels in the absence of tempo shifts. Birth replacement decomposition provides the link to the effects of current fertility levels on generation replacement, no matter what are the reasons why the TFR is at current levels. Therefore, both decompositions are compatible and complementary since they operate in different directions.

## APPENDIX: NRR AND NBRR IN A STABLE POPULATION

A stable population is characterized by fixed survivors and fertility age-schedules, $l_x$ and $f_x$. For simplicity we will assume a one-sex population throughout. Given such elements the number of births at a particular time is connected to the number of births in the past through the renewal equation:

$$B_t = \int l_x f_x B_{t-x} \, dx = \int l_x f_x e^{-rx} B_t \, dx$$

Lotka's integral equation is based on the substitution of $B_{t-x}$ by $e^{-rx} \cdot B_t$. $r$ as shown in the second expression. The intrinsic growth rate, $r$, is the real solution to that integral equation (Preston, Heuveline and Guillot, 2001). The NRR would take the following form:

$$\text{NRR} = \int l_x f_x \, dx$$

The NBRR, in its turn, is defined as:

$$\text{NBRR} = B_t / [\int f_x B_{t-x} dx / \int f_x dx] = \int f_x dx / \int f_x e^{-rx} dx$$

We can see here the differences between both concepts: while the NRR looks at population replacement by computing the number of births occurring to a new entrant to the population, the NBRR can be seen as the inverse of the weighted ratios between births in the mother's generation and births at present. It does not incorporate explicitly mortality (only implicitly thru its effects on $r$). Note that both indicators are equal to 1 when the NRR is equal to 1 (and $r$ equal to zero). They will both be bigger than one when $r$ is positive and smaller than one when $r$ is negative. The particular comparison depends on the $l_x$ and $m_x$ schedules, but empirical comparison shows that their values are extremely close. Appendix table 1 shows the comparison between the NRR and the NBRR for a set of stable populations covering most of the range of human populations. The NRR and the NBRR are virtually undistinguishable. Differences appear only at the second decimal point or later.

In conclusion, both indexes behave in the same fashion for stable populations. It is only when populations are not stable that they behave differently.

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Table 1. Replacement, fertility and generation size indicators around 2000.

| *Country* | *Year* | *G* | *TFR* | *BG* | *BRR* | *NBRR* |
|---|---|---|---|---|---|---|
| Albania | 1999 | 28.5 | 2.11 | 34.5 | 1.74 | 0.85 |
| Argentina | 2000 | 275.7 | 2.48 | 290.5 | 2.35 | 1.15 |
| Australia | 2000 | 142.7 | 1.75 | 118.4 | 2.11 | 1.03 |
| Belarus | 2001 | 71.9 | 1.28 | 74.3 | 1.23 | 0.60 |
| China | 2001 | 13758.6 | 1.39 | 11682.3 | 1.63 | 0.80 |
| Cuba | 2000 | 90.2 | 1.59 | 101.1 | 1.42 | 0.69 |
| Dominican Republic | 1999 | 64.6 | 2.93 | 89.7 | 2.11 | 1.03 |
| France | 1999 | 431.1 | 1.79 | 404.0 | 1.91 | 0.94 |
| Iran (Islamic Republic of) | 2000 | 542.7 | 2.17 | 669.3 | 1.76 | 0.86 |
| Italy | 2000 | 432.1 | 1.24 | 433.9 | 1.24 | 0.60 |
| Japan | 2000 | 870.3 | 1.35 | 925.2 | 1.27 | 0.62 |
| Morocco | 1999 | 178.2 | 2.97 | 323.1 | 1.64 | 0.80 |
| Romania | 2000 | 168.6 | 1.31 | 195.0 | 1.13 | 0.55 |
| Spain | 2000 | 328.8 | 1.24 | 323.4 | 1.26 | 0.62 |
| Switzerland | 2001 | 52.1 | 1.41 | 46.1 | 1.59 | 0.78 |
| Turkey | 2000 | 554.6 | 2.48 | 712.0 | 1.93 | 0.94 |
| Uganda | 1999 | 176.0 | 6.97 | 241.0 | 5.09 | 2.49 |
| United Kingdom | 2000 | 406.1 | 1.65 | 405.9 | 1.65 | 0.81 |
| United States of America | 2000 | 1894.5 | 2.13 | 1759.1 | 2.29 | 1.12 |
| Zambia | 2000 | 76.4 | 5.87 | 110.8 | 4.05 | 1.98 |

*Notes*: G – Mean mother's generation size (in thousands), TFR – Total Fertility Rate, BG – Mean mother's generation size at birth (in thousands), BRR – Birth Replacement Ratio, NBRR – Net Birth Replacement Ratio. See text for detailed definitions.
*Sources:* Own calculations based on United Nations data. Age-specific fertility rates (by age group), from World Fertility Report 2003, quinquennial births 1950-1985 from World Population Prospects, births around 2000 from World Fertility Report 2003, World Population Prospects 2003 (Uganda, Zambia, average of 1995-2000 and 2000-2005), Demographic Yearbook, 2002 (Morocco).

Table 2. Birth Replacement Ratios decomposition in Spain, 1996-2004.

| Year | 1996 | 1997[1] | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004[2] |
|---|---|---|---|---|---|---|---|---|---|
| G | 315 | 317 | 318 | 322 | 328 | 334 | 342 | 347 | 352 |
| BG | 324 | 324 | 324 | 323 | 322 | 320 | 318 | 315 | 309 |
| $G^{Surv}$ | 310 | 310 | 311 | 310 | 310 | 308 | 307 | 305 | 299 |
| $G^{Nat}$ | 307 | 309 | 310 | 312 | 314 | 314 | 313 | 312 | 312 |
| $G^{For}$ | 8 | 8 | 8 | 10 | 14 | 21 | 28 | 35 | 40 |
| $B^f$ | 176 | 179 | 176 | 184 | 192 | 198 | 203 | 214 | 219 |
| B | 363 | 369 | 365 | 380 | 398 | 406 | 419 | 442 | 453 |
| TFR | 1.15 | 1.16 | 1.15 | 1.18 | 1.21 | 1.21 | 1.23 | 1.27 | 1.29 |
| BRR | 1.12 | 1.14 | 1.13 | 1.18 | 1.23 | 1.27 | 1.32 | 1.40 | 1.47 |
| NBRR | 0.54 | 0.55 | 0.54 | 0.57 | 0.60 | 0.62 | 0.64 | 0.68 | 0.71 |
| $\overline{\lambda}_t$ | 0.956 | 0.957 | 0.958 | 0.960 | 0.962 | 0.964 | 0.965 | 0.967 | 0.969 |
| $K^{Emig}$ | 0.009 | 0.005 | 0.001 | -0.006 | -0.013 | -0.017 | -0.021 | -0.024 | -0.041 |
| $P^{For}$ | 0.025 | 0.025 | 0.025 | 0.031 | 0.043 | 0.062 | 0.083 | 0.101 | 0.115 |
| $K^{NetMigr}$ | 0.017 | 0.021 | 0.025 | 0.037 | 0.059 | 0.084 | 0.114 | 0.138 | 0.176 |

*Notes*: In thousands: G – Mean mother's generation size, BG – Mean mother's generation size at birth, $G^{Surv}$– Expected survivors, $G^{Nat}$ – Native-born potential mothers, $G^{For}$ – Foreign-born potential mothers, $B^f$ – Female births, B – Births; TFR – Total Fertility Rate, BRR – Birth Replacement Ratio, NBRR – Net Birth Replacement Ratio. $\overline{\lambda}_t$ – Mean survival, $K^{Emig}$ – Emigration factor, $P^{For}$ – Proportion foreign-born, $k^{NetMigr}$ – Net Migration Factor. See text for detailed definitions.

*Sources:* Own calculations based on data from the Instituto Nacional de Estadística (INE): Female population figures by age and place of birth from the *Padrón Municipal* for 1996 (May 1st), 1998 to 2005 (Jan 1st). Birth counts by cohort, year and sex from the *Movimiento Natural de la Población*, years 1996 to 2003, and total births and female births, 1946 to 2004. For 2004 only total number of births is available. Cohort mortality tables: Own calculations based on data from *Human Mortality Database*.

[1] – Figures for G obtained by linear interpolation between 1996 and 1998.

[2] – Figures for G obtained using the same fertility schedule as observed in 2003.

Table 3. Comparison of Native and Foreign-born population in Spain: 1998 and 2003

| | Native Born | | | | Foreign Born | | |
|---|---|---|---|---|---|---|---|
| Cohorts | At birth | 1998 | 2003 | Δ 98-03 | 1998 | 2003 | Δ 98-03 |
| 1984-88 | 1066570 | **1090125** | **1112052** | 2.01% | 23815 | 70108 | 194.39% |
| 1979-83 | 1301542 | **1399322** | **1403187** | 0.28% | 30016 | 77920 | 159.59% |
| 1974-79 | 1610569 | 1592548 | 1595451 | 0.18% | 49170 | 157363 | 220.04% |
| 1969-73 | 1625692 | 1530166 | 1545648 | 1.01% | 73698 | 218274 | 196.17% |
| 1964-69 | 1649683 | 1525557 | 1546157 | 1.35% | 86661 | 220019 | 153.88% |
| 1959-63 | 1604002 | 1447284 | 1462884 | 1.08% | 64890 | 195905 | 201.90% |
| 1954-59 | 1503718 | 1292081 | 1299041 | 0.54% | 48767 | 140752 | 188.62% |

*Note:* Bold indicates population counts for those birth cohorts larger than generation size. Δ 98-03 indicates percentage change in population counts between 1998 and 2003.
*Sources:* Births from *Movimiento Natural de Población* and population counts from *Padrón Municipal* for 1998 and 2003, Instituto Nacional de Estadística (INE).

Table 4. Decomposition of TFR by country of citizenship and imputed reconstruction for Spanish born.

| | | 1996 | 1997[1] | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004[2] |
|---|---|---|---|---|---|---|---|---|---|---|
| Spanish citizenship | G | 309496 | 310361 | 311230 | 313221 | 315257 | 315097 | 314715 | 313629 | 312903 |
| | F | 1.13 | 1.14 | 1.12 | 1.15 | 1.18 | 1.18 | 1.19 | 1.24 | 1.25 |
| Foreign citizenship | G | 5753 | 6485 | 7214 | 8740 | 12726 | 19381 | 27159 | 33597 | 39765 |
| | F | 2.06 | 2.16 | 2.13 | 2.12 | 1.94 | 1.73 | 1.63 | 1.61 | 1.56 |
| European | G | 2444 | 2698 | 2952 | 3429 | 4215 | 5627 | 7773 | 9824 | 12208 |
| | F | 1.56 | 1.62 | 1.53 | 1.50 | 1.49 | 1.36 | 1.28 | 1.30 | 1.22 |
| American | G | 1827 | 2090 | 2352 | 2984 | 5450 | 9781 | 14386 | 17904 | 20719 |
| | F | 1.80 | 1.80 | 1.79 | 1.82 | 1.53 | 1.44 | 1.40 | 1.36 | 1.30 |
| African | G | 1079 | 1247 | 1414 | 1758 | 2333 | 3030 | 3790 | 4441 | 5153 |
| | F | 3.31 | 3.73 | 3.77 | 3.69 | 3.53 | 3.20 | 3.03 | 3.13 | 3.22 |
| Rest of the world | G | 402 | 449 | 495 | 569 | 729 | 942 | 1209 | 1428 | 1685 |
| | F | 2.92 | 2.73 | 2.62 | 2.54 | 2.47 | 2.23 | 2.15 | 2.05 | 2.20 |
| *Particular countries* | | | | | | | | | | |
| Romania | G | 20 | 26 | 31 | 60 | 239 | 623 | 1326 | 2299 | 3570 |
| | F | 3.92 | 3.54 | 4.27 | 4.12 | 2.28 | 1.60 | 1.55 | 1.59 | 1.38 |
| Morocco | G | 800 | 920 | 1041 | 1305 | 1707 | 2177 | 2699 | 3164 | 3666 |
| | F | 3.38 | 3.84 | 3.90 | 3.80 | 3.66 | 3.38 | 3.28 | 3.37 | 3.53 |
| Argentina | G | 195 | 200 | 204 | 223 | 293 | 503 | 997 | 1478 | 1759 |
| | F | 1.67 | 1.52 | 1.35 | 1.37 | 1.31 | 1.49 | 1.38 | 1.24 | 1.19 |
| Colombia | G | . | . | . | . | . | 2458 | 3713 | 4141 | 4256 |
| | F | . | . | . | . | . | 1.19 | 1.32 | 1.20 | 1.15 |
| Ecuador | G | . | . | . | . | . | 3245 | 4998 | 6352 | 6988 |
| | F | . | . | . | . | . | 1.74 | 1.68 | 1.66 | 1.58 |
| Spanish-born | G | 307237 | 308818 | 310398 | 312135 | 313876 | 313779 | 313487 | 312297 | 311573 |
| (Imputed) | F | 1.11 | 1.12 | 1.09 | 1.12 | 1.15 | 1.10 | 1.08 | 1.10 | 1.11 |

*Notes*: G – Group-specific mean mother's generation size, F – Group-specific fertility index. See text for detailed definitions.

*Sources:* Own calculations based on data from the Instituto Nacional de Estadística (INE): Female population figures by age and place of birth from the *Padrón Municipal* for 1996 (May 1st), 1998 to 2005 (Jan 1st). Birth counts by cohort, year and mothers' citizenship from the *Movimiento Natural de la Población*, years 1996 to 2003.

[1] – Figures for G obtained by linear interpolation between 1996 and 1998.

[2] – Figures for G obtained using the same fertility schedule as observed in 2003.

Appendix Table 1. NRR and NBRR for stable populations

| | | Mortality | | |
|---|---|---|---|---|
| | | High | Medium | Low |
| | *r* | -0.0439 | -0.0323 | -0.0260 |
| | *NRR* | 0.2946 | 0.4072 | 0.4849 |
| **TFR=1** | *NBRR* | 0.2901 | 0.4046 | 0.4848 |
| | *r* | -0.0193 | -0.0075 | -0.0011 |
| | *NRR* | 0.5892 | 0.8144 | 0.9699 |
| **TFR=2** | *NBRR* | 0.5853 | 0.8132 | 0.9698 |
| | *r* | -0.0046 | 0.0074 | 0.0138 |
| | *NRR* | 0.8838 | 1.2216 | 1.4548 |
| **TFR=3** | *NBRR* | 0.8825 | 1.2233 | 1.4550 |
| | *r* | 0.0061 | 0.0182 | 0.0246 |
| | *NRR* | 1.1784 | 1.6288 | 1.9397 |
| **TFR=4** | *NBRR* | 1.1808 | 1.6344 | 1.9402 |

*Note:* Sex ratio at birth assumed to be 0.4886.
*Source:* Author's calculations based on female Swedish life tables from the Human Mortality Database (2005) for 1751, 1920 and 2000 – Lx – ; and rescaled US fertility rates by single year of age calculated from NCHS (2005) – births, year 2000 – and U.S. Census Bureau (2005) – female population as of july 2000 –.

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