Taxation, Expenditures and the Irish Miracle*

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Abstract

We examine the role of fiscal policy in accounting for the remarkable rise of Ireland from one of Western Europe's poorest countries to one of its richest in just a few years. We focus on the importance of business tax reform and overall changes in fiscal policy, in conjunction with other factors, which we model as a residual rise in Total Factor Productivity (TFP). We conduct our analysis using a two-sector, small open economy model where production requires tangible and intangible capital services, and where inflows of capital are limited by a collateral constraint (disciplined to account for the GNP to GDP gap). We find that the much discussed reductions of business taxes played a significant, but secondary, role in the Irish miracle. However, tax reform and other changes strongly reinforce each other. We also find that Ireland's openness to capital movements was crucial: under the same driving forces, a closed economy would have experienced a significantly smaller rise in GDP.

Keywords: Ireland; Corporate Taxation; Fiscal Policy; Economic Development.

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1 Introduction

In 1980, Ireland's output per adult was about 49% of the United States level in PPP terms. By 2005, Ireland was among the richest countries in the world, with a level of output per adult even higher than that of the United States (about 105%). Employment increased substantially in the same period. The employment rate went from 58 to 68 percent of the adult population and hours worked per adult increased by about 15 percent.[1] This is a phenomenal performance that has not been sufficiently investigated in the macroeconomic literature. We refer to it as the *Irish miracle*.

In this paper, we assess the quantitative significance of policy-driven factors that may have contributed to the Irish miracle. In particular, we concentrate on two key factors: gradually falling taxes on business income and a fall in government consumption and transfers relative to output. We analyze these factors in isolation and in conjunction with a residual rise in Total Factor Productivity (TFP). We ask: what is the quantitative importance of the drastic changes in business taxation in Ireland? What is the role of overall changes in taxation and expenditures? How do these changes interplay with changes in TFP in the context of an economy open to capital flows?

Drastic changes in business taxation accompanied the remarkable output growth performance of Ireland during the period that we study. In the 1980s, a gradual but eventually large reduction in tax rates on business income began. Starting at 50% on non-manufacturing business income, a rate of 12.5% was reached in 2003 and remains in place today. The special tax treatment of the manufacturing sector was abolished; by 2003 all sectors were taxed at the same rate. The current rate of 12.5% is the lowest among OECD member countries. Figure 1 exhibits these large changes alongside the changes in Irish GDP per adult. At the same time, other changes in fiscal policy took place, with changes in labor and consumption tax rates and the size of the government sector changing as a share of output. While government transfers remained relatively constant at 9% of GDP, government consumption fell as a share of output by about six percentage points, from

[1] We focus on "per adult" statistics since Ireland went through a very noticeable demographic transition during the period we are interested in, resulting in a larger fraction of people aged 15-64 in the population. Specifically, that fraction went up from 58.5 to 67.8 percent.

about 20% in 1980 to 14% in 2005. Meanwhile, as the Irish economy took off, a substantial amount of foreign capital flowed in, and a gap between GDP and GNP gradually widened. While in 1980, Ireland's GNP was about 97 percent of its GDP, it was about 86 percent by 2005. This is a large gap by any reasonable empirical standard.

—Figure 1 about here—

Given the emerging gap between GDP and GNP, it would be inappropriate to analyze the Irish experience in a closed-economy model. Hence, we conduct our analysis in the context of a small open economy where capital movements are limited by a collateral constraint as in Barro et al. (1995). In our model economy, a representative household enjoys a final consumption good and dislikes work. The final consumption and investment good is produced via the aggregation of two intermediate goods produced in different sectors, m and s. Production of each of these goods requires labor and services of standard or *tangible* capital, as well as *intangible* capital services. Motivated by the Irish experience, the two intermediate goods differ in terms of their tax treatment; the sector-specific business tax rates follow distinct paths over time. In sector m (manufacturing), tax rates are initially low and essentially unchanged over time. In the s sector (services or, rather, everything but manufacturing), tax rates are initially high and subsequently drop gradually. The government in this economy also taxes labor income, issues debt, consumes and provides transfers to the representative household.

We set the initial conditions of our economy to reproduce the conditions of the Irish economy circa 1980. We then impose, from the data, the time path for the tax rates on business income by sector, the time path of labor and consumption tax rates, as well as the time path of government consumption and transfers as shares of output. We force the model to reproduce key aspects of the transition of Irish economy from 1980 to 2005. Specifically, we force the model to reproduce (i) the GNP to GDP ratio and (ii) the time path of output per adult (relative to a two percent annual growth trend). In doing so, we infer the (residual) increase in TFP and the tightness of the collateral constraint. Strikingly, our model also reproduces with a great degree of accuracy the path for hours of work and consumption; this is reassuring because we did not force the model to match the data

along these dimensions.

Findings Our results show that the much discussed changes in business taxation in Ireland played a significant, but secondary, role in the Irish miracle. We find that if changes in tax rates had been the *only* factor changing in the period, Irish output per adult would have increased by only 23% relative to trend—only a bit more than a fifth of the observed change in 2005. Second, we find that the entire package of fiscal policy changes had somewhat more significant consequences. Changes in all taxes, government consumption and transfers together lead to hypothetical changes in output per adult of about 27% relative to trend. Third, our model implies only modest increases in TFP—about 25%—to generate the observed changes in GDP between 1980 and 2005. Nevertheless, we find that the inferred changes in TFP were a dominant force in the Irish context. We find that these TFP changes in isolation would have led to a substantial increase in output per adult—about 76%. We also find that modeling Ireland as a small open economy is critical in this context. If the Irish economy had been closed, the driving forces that replicate the Irish miracle in the context of an open economy (our benchmark scenario) would, by 2005, have led to an increase in output per adult relative to trend of *less than half* of the observed change. Finally, we find that if agents are myopic, the same driving forces account for about 74% (87 percentage points) of the output changes in the benchmark (perfect foresight) case.

There are three important lessons from our analysis that are relevant for understanding development episodes more generally. Firstly, reductions in business taxes can lead to quantitatively substantial and fast output gains in the context of an open economy. Secondly, fiscal policy changes and other changes strongly reinforce each other in the context of an open economy. Finally, openness to capital movements is crucial for reproducing the facts. As we explain in Section 4, a closed economy model would not have been able to replicate the gradual rise in hours worked or the gradual decline in the consumption/output ratio, even qualitatively.

Related Work Our work contributes to a large literature that uses versions of the growth model to better understand historical episodes, and, in particular, to examine the significance of fiscal policy. An early prominent contribution to this literature is Crucini and

Kahn (1996) who used a growth model to measure the quantitative importance of tariffs for the Great Depression. Ohanian (1997) and McGrattan and Ohanian (2010) studied the role and effects of fiscal policy in wartime. Similarly, Cooley and Ohanian (1997) studied the role of capital income taxes in accounting for the postwar stagnation of the UK.

Our paper is also related to the literature on international tax competition, particularly to the few analyses available in a dynamic context. Examples are Correia (1996) and particularly Gross et al. (2019), where a main result is that source-based taxes on capital income should gradually decline—as indeed they did in Ireland.

Finally, our work is also connected to a literature trying to make sense of Ireland's recent economic history. Honohan and Walsh (2002) provided a compelling narrative account of Ireland's rise, emphasizing the importance of fiscal policy reform. Ahearne et al. (2006) studied Ireland's stagnation from 1973 to 1985, i.e. the pre-reform era. The purpose of Barry and Devereux (2006) is closer to ours: to use theory to assess the relative significance of various factors in accounting for Ireland's more recent rise. However, their emphasis is quite different; they examine the importance for Ireland of having a common labor market with the rest of the EU and argue that the influx of labor from abroad during the 1990s made a significant difference for the growth in GDP. We instead focus on output *per adult*, not on total output, and take demographic changes as given. In this sense, our work is best viewed as complementary to theirs.

Our analysis proceeds as follows. In Section 2, we document in detail the changes in the Irish economy in the period 1980-2005. In Section 3, we present our model. In Section 4, we assign parameter values to the model. In Section 5, we analyze the quantitative implications of changes in taxation and fiscal policy, and in TFP for the Irish economy. In Section 6, we put our main findings in perspective. Finally, in Section 7, we conclude.

2 Ireland 1980-2005: Key Facts

Below, we summarize facts that characterize the spectacular rise of Ireland in the period 1980-2005. We place these facts in perspective in a global and European context. For cross-country comparisons, we use data at international prices from the Penn World Tables 8.1.

The Output Miracle In order to remove the effects of demographic swings (population increase, changing age composition), we focus on output per working-age adult (ages 15-64), or *per adult* for short.[2] From 1980 to 2005, Ireland's GDP per adult increased by a factor of nearly 3.5, at an average annual rate of about 5.1 percent. Ireland's GDP per adult went from about 49 percent of that of the United States to about 105 percent, implying a growth relative to the United States of about 113 percent from 1980 to 2005. Figure A1 in the Online Appendix illustrates this fact. Though Ireland's growth was high from 1980 onwards, there was a marked acceleration starting in 1992-93. From 1992 to 2005, GDP per adult grew at an average annual rate of 6.9 percent.[3] Note that, prior to 1980, Ireland was fairly stable relative to the United States. For instance, in 1975, Ireland's GDP per adult was 43 percent of that in the United States. Nothing approaching this impressive growth rate was experienced by any of the other member countries of the European Union (EU) that joined before 2000. Indeed, even among those who joined later, only Poland's experience is comparable.

Much of measured output's rise in Ireland was fueled by foreign investment. According to the World Bank, the average net inflow of foreign direct investment into Ireland grew significantly over time. As a percentage of a (growing) GDP, the net inflow averaged about 4.8 percent between 1980 and 2005; between 1998 and 2005, it averaged 14.8 percent.[4] As a result, a gap opened up between GDP and GNP, with a gradually shrinking GNP/GDP ratio. This ratio declined from about 97 percent to about 86 percent between 1980 and 2005. Figure A2 in the Online Appendix illustrates the path of the GDP/GNP ratio in Ireland.

There is a concern that the Irish miracle is overstated because of the profit-shifting activities of multinational corporations. What would be an upper bound for this phenomenon? From national income accounts, we know that before-tax profits constituted about 22.3 percent of GDP in 1995, 28.5 percent in 2000 and 26.6 percent in 2005. Accord-

[2]Our source for the number of adults in Ireland is the OECD.

[3]In per capita terms, Ireland's growth was even more spectacular. Between 1980 and 2005, GDP per capita grew at an average annual rate of 5.7 percent as the adult share of the population increased.

[4]See World Bank (2017). This inflow has no parallel in Western Europe at the time. For instance, in the case of Spain that we return to later on, this inflow averaged 2.2% of GDP between 1980 and 2005; between 1998 and 2005, it averaged 3.8 percent.

ing to Tørsløv et al. (2018), about two thirds of these profits are accounted for by firms the majority of whose owners reside outside of Ireland; this statistic is from 2015. Assuming that this number was valid for earlier years as well, profits by foreign-owned companies amounted to about 14.9 percent of GDP in 1995; in 2000, the number was 19 percent, and in 2005, it was 18.4 percent. Assuming that *all* these profits were shifted from abroad, obviously an extreme assumption, we have a plausible upper bound for shifted profits. Hence, GDP statistics are overstated by at most 14.9 percent, 19 percent and 18.4 percent in 1995, 2000, and 2005, respectively. Indeed, this upper bound is likely a generous one given that the fraction of profits accounted for by foreign firms probably increased over time as business taxes were reduced.[5]

Hours Worked and Demographics The dramatic changes in output documented above were accompanied by large changes in employment and hours of work. The employment rate increased from 1980 to 2005; from about 57.6 percent to 68.3 percent.[6] Overall, total hours worked per adult fell from 1980 to 1985 and then increased gradually to a level about 30% higher than in 1985. It is worth noting that the initial drop in hours per adult was substantial, with the trough about 15 percent below the value in 1980.

The observed changes in hours worked were accompanied by non-trivial demographic changes. While the total population grew at a modest pace in the period 1980-2005 at about 0.8 percent per annum, the adult population grew more substantially, with an annual increase of about 1.4 percent in the period—a factor of about 1.4 over 25 years.

Government Spending Government spending (consumption plus transfer payments) fell as a fraction of GDP during the period 1980-2005, from about 29 to about 24 percent. Essentially all of that reduction came from government purchases, whose share of GDP fell from 20 percent to 14 percent. Transfers remained roughly constant as a share of output.

[5]Blanchard (2002) uses OECD data to document the quantitative significance of foreign profits in Ireland. He finds that they amount to no more than 10 percent of GDP.

[6]We define the employment rate as a fraction of the population 15-64 years old in a given year. For participation and hours worked data, we use data on persons engaged provided by the EU KLEMS database. See http://www.euklems.net/.

Tax Rates Tax rates on business income fell significantly in the period 1985-2005. We refer to these rates—as others do—as 'corporate' income tax rates. Until 1985, Ireland had a statutory tax rate that at 50 percent was comparable to those of other West European countries, though the manufacturing sector enjoyed a much lower (effective) corporate rate than the statutory one. In the 1990s, a process of reduction and harmonization took place. By 1995, the statutory corporate income tax rate had been reduced significantly and was already competitive at 38 percent. The reduction continued apace, with the statutory rate falling to 24 percent in 2000, 20 percent in 2001, 16 percent in 2002 and, finally, 12.5 percent in 2003. The rate has not changed after that. Table A1 in the Online Appendix presents the time path of corporate rates in Ireland. Figure 2 below illustrates the pattern of statutory rates in this period and compares them with other countries.

—Figure 2 about here—

There were significant changes as well in consumption and labor taxes between 1980 and 2005. Using Irish tax revenue data, we compute effective tax rates on labor income and consumption, τ^L and τ^C. We find that the tax rate on labor income was noticeably higher in 2005 than in 1980. It went up sharply from 21.9% to 31.9% from 1980 to 1988. It then fell somewhat, and remained roughly constant from 1995 onwards at a rate of about 27.5%. The consumption tax rate also increased over the period 1980-2005. It was roughly constant until 1992-93 at about 25.5%, and then it gradually rose to about 30%. It is useful to summarize the changes in consumption and labor taxes via a single consumption/leisure tax wedge, $\widetilde{\tau}_t$. We calculate it each date via the formula $1 - \widetilde{\tau}_t = (1 - \tau_t^L)/(1 + \tau_t^C)$. The value for $\widetilde{\tau}$ rose from 35.7% in 1980 until the late eighties, and then remained approximately constant at about 43-44%. Table A1 in the Online Appendix summarizes the information on tax rates.

2.1 Relevance

The Irish miracle is relevant for the study of development because it is so rare for a country to move from the middle of the world income distribution to the top. Most growth miracles are concerned with economies that were poor after World War II (e.g. Hong

Kong, Singapore, South Korea, Taiwan), or were destroyed by war but had been relatively rich in the past (e.g. West Germany and Japan). Ireland is a spectacular case of a phenomenon that is surprisingly rare: a middle-income economy turning quickly into a rich one. Indeed, commonly discussed experiences involve relative stagnation at middle income or high middle-income levels (e.g. Mexico, Brazil, Turkey) or relative decline (e.g. Argentina, Uruguay). Many authors have referred informally to this phenomenon in different ways as the *middle income trap*.

The singular success of Ireland perhaps stands out most clearly by comparing it to Spain, a country with a similar level of development around 1980 and that was *also* under the policy regime of the EU. Spain experienced nothing like Ireland's growth spurt during the period that we study. In 1980, Ireland had a level of output per adult about 4.5 percent *lower* than Spain's, while the level of output per worker was about 15 percent lower. In 1995, Ireland's output per adult was about 27 percent higher than Spain's. Ten years later, Ireland's output per adult was about 75 percent higher than Spain's.

In other ways, Ireland and Spain went through similar transformations. Around 1985, agriculture accounted for about 15 percent of employment in both Spain and Ireland. By 2005 that number had fallen to about 5 percent in both countries. Both countries also experienced large demographic transitions between 1980 and 2005. As noted earlier, the share of adults 15-64 years old in the population of Ireland went from about 58.9 percent to 68.9 percent; the corresponding Spanish numbers were 52.5 percent and 63.7 percent. Finally, the educational attainment of the workforce increased in both countries, albeit at different rates. As we noted earlier, in Ireland average years of schooling went from around 9.9 in 1980 to about 11.9 years in 2005, or by about two years. In Spain, the increase was much stronger. Average years of schooling increased by more than *five* years; they went from about 5.5 in 1980 to 10.8 in 2005.

It therefore seems far-fetched to attribute the differential performance of Spain and Ireland to either demographic factors, different speeds of structural transformation or to a rapid increases in the schooling attainment of the workforce. Indeed, in light of these factors, a development miracle probably had somewhat better odds in Spain than in Ireland.

3 The Model

We now present our model economy. First we provide an outline of the model and provide some justification for our modeling choices. Then we describe the model in detail.

A two-sector economy with two types of capital The model features two sectors, a manufacturing sector and a non-manufacturing (or service) sector. These sectors produce imperfectly substitutable goods that are combined to produce the final good. This final good serves as a consumption good, a tangible investment good and an intangible investment good.

The distinction between manufacturing and services is there to enable us to reproduce the fact that in Ireland, from the early 1980s until 2003, manufacturing was treated more leniently than other sectors when it came to corporate taxation.

The presence of intangible capital in production is motivated by the work of Corrado et al. (2006), Kapicka (2012), Hall (2001), McGrattan and Prescott (2010) and McGrattan and Prescott (2017), among many others, who have documented the empirical relevance of multiple forms of intangible capital and argued for its importance in accounting for macroeconomic phenomena. It is especially relevant for our analysis, since as documented above, the Irish miracle was to a large extent driven by large flows of investment from abroad. Given the large extent to which these inflows were associated with the pharmaceutical and IT sectors,[7] it is not hard to believe that they were accompanied by the arrival of blueprints, brands, developed production methods, etc., that are valuable in the production process.

For our purposes, an additional reason for incorporating intangible capital into our model is that it provides an empirically plausible amplification mechanism—its presence tends in the direction of attributing larger significance to business tax reform and government spending (purchases and transfers) reform, leaving relatively less for changes in residual TFP to account for.

[7] See for instance Central Statistics Office, Ireland (2011).

The collateral constraint To avoid instantaneous transitions from one balanced growth path to another, and, more importantly, to avoid counterfactually large gaps between GDP and GNP, we introduce a friction affecting international capital flows. The approach follows that of Barro et al. (1995). Specifically, international borrowing has to be backed by collateral, which is a given fraction (possibly greater than one) of tangible capital; intangible capital (or government bonds) cannot be used as collateral at all. This implies that, along a transition path, rates of return may differ across different assets, with domestic government bonds and intangible capital earning the highest rate of return, as we explain below.

3.1 Details

A representative household has preferences over consumption (c) and hours worked (h) represented by

$$\sum_{t=0}^{\infty} \beta^t \left(\ln c_t - h_t^{1+1/\varepsilon} \right) \tag{1}$$

where $\psi > 0$ and $\varepsilon > 0$. The parameter ε is the (constant) Frisch elasticity of labor supply. The household faces the constraint

$$c_t + a_{t+1} + q_t b_{t+1} + k_{t+1} + z_{t+1} = \widehat{w}_t h_t + \widehat{R}_t^k k_t + \widehat{R}_t^z z_t + R^a a_t + b_t + \mathcal{T}_t. \tag{2}$$

The variable a_t stands for (holdings of) foreign bonds, b_t is domestic government bonds, k_t is tangible capital and z_t is intangible capital. Also, R_t^k is the pre-tax rate of return on physical capital, q_t is the price of government bonds, R^a is the (constant) world interest rate and R_t^z is the pre-tax rate of return on intangible capital. Hats over rates of return indicate that the rates in question are after-tax. Notice that bond returns are *not* taxed; only labor, intangible and physical capital returns are subject to taxation.[8] $\mathcal{T}_t$ is a lump-sum transfer payment.

The representative household is also subject to the following collateral constraint:

$$a_{t+1} + \varphi k_{t+1} \geq 0. \tag{3}$$

[8]This is mainly a matter of notational convention rather than substance.

The constraint states that a fraction φ of physical capital can be used as collateral; no intangible capital can be used for that purpose. Nor can government bonds be used as collateral, reflecting the fact that they do not constitute net wealth. It follows that the representative household maximizes (1), subject to (2), (3) and $k_0 > 0$, $z_0 > 0$ and a_0 given.

In the absence of a collateral constraint, after-tax rates of return would equalize across all assets: foreign bonds, domestic government bonds, physical capital and intangible capital. In the presence of a collateral constraint, these returns only equalize in the long run but may differ in the short run; if the collateral constraint binds in any period, then those rates of return are distinct in that period, except for the rates of return on intangible capital and government bonds, which are always equal.

Production The final (consumption and investment) good is produced according to

$$Y_t = \bar{A}_t[\alpha_s Y_{s,t}^{\xi} + (1-\alpha_s)Y_{m,t}^{\xi}]^{1/\xi} \tag{4}$$

where $\bar{A}_t$ is exogenously given productivity (TFP), Y_s is the output of the s sector and Y_m is the output of the m sector and where $-\infty < \xi < 1$. $\xi \to 0$ corresponds to the Cobb-Douglas case.

Intermediate goods production requires three inputs under constant returns to scale: labor, tangible capital and intangible capital. Output in the $i = m, s$ sector is produced according to

$$Y_{i,t} = K_{i,t}^{\theta_k} Z_{i,t}^{\theta_z} H_{i,t}^{1-\theta_k-\theta_z}, \quad i = m, s \tag{5}$$

Taxation Labor is taxed at a time-varying rate τ_t so that $\widehat{w}_t = (1-\tau_t)w_t$, where w_t is the pre-tax wage. Income from physical capital in the s sector is taxed at a possibly time-varying rate τ_t^s and, similarly, income from physical capital in the m sector is taxed at a possibly time-varying rate τ_t^m so that

$$\widehat{R}_t^{k,s} = 1 + r_t^{k,s} - \delta_k - \tau_t^s(r_t^{k,s} - \delta_k) \quad \text{and} \quad \widehat{R}_t^{k,m} = 1 + r_t^{k,m} - \delta_k - \tau_t^m(r_t^{k,m} - \delta_k),$$

where $r_t^{k,s}$ and $r_t^{k,m}$ are the rental rates of physical capital in the s and m sectors, respectively, and δ_k is the depreciation rate of tangible capital.

Income from intangible capital is taxed according to the same principles—and at the same rates—as income from tangible capital. Thus,

$$\widehat{R}_t^{z,s} = 1 + r_t^{z,s} - \delta_z - \tau_t^s(r_t^{z,s} - \delta_z) \quad \text{and} \quad \widehat{R}_t^{z,m} = 1 + r_t^{z,m} - \delta_z - \tau_t^m(r_t^{z,m} - \delta_z),$$

where δ_z is the depreciation rate of intangible capital.

Equilibrium In equilibrium, the aggregate uses of capital and labor must satisfy:

$$Z_t = Z_{m,t} + Z_{s,t}, \quad K_t = K_{m,t} + K_{s,t}, \quad \text{and} \quad H_t = H_{m,t} + H_{s,t}$$

The flow budget constraint for the government is given by:

$$B_t + G_t + \mathcal{T}_t = \tau_t w_t H_t + \sum_{i\in\{m,s\}} \tau_t^i(r_t^{k,i} - \delta_k)K_{i,t} + \sum_{i\in\{m,s\}} \tau_t^i(r_t^{z,i} - \delta_z)Z_{i,t} + q_t B_{t+1} \tag{6}$$

with the limiting condition

$$\lim_{t\to\infty} \left(\prod_{k=0}^{t-1} q_k\right) B_t = 0 \tag{7}$$

where G_t stands for government consumption at date t, B_t is government debt inherited from period $t-1$ (or exogenously given in period 0) and q_t is the price of government bonds issued in period t. Notice that the first term on the right stands for tax collections out of labor income, whereas the second and third terms stand for revenues from taxes on tangible and intangible capital in both sectors.

We now state the various conditions that need to hold in a competitive equilibrium. The rental rates of capital used in both intermediate sectors are equal to the values (in terms of the final good) of the corresponding marginal products of capital:

$$r_t^{k,s} = q_{s,t}\theta_k Y_{s,t}/K_{s,t} \quad \text{and} \quad r_t^{k,m} = q_{m,t}\theta_k Y_{m,t}/K_{m,t},$$

where $q_{s,t}$ is the price of the s good in terms of final goods and similarly with $q_{m,t}$. These prices, in turn, are defined by the marginal product of the m good and the s good in the final goods sector, respectively, so that for $\Upsilon_t := \left(\alpha_s Y_{s,t}^{\xi} + (1-\alpha_s)Y_{m,t}^{\xi}\right)$

$$q_{s,t} = \bar{A}_t\left(\Upsilon_t\right)^{1/\xi-1}\alpha_s Y_{s,t}^{\xi-1} \quad \text{and} \quad q_{m,t} = \bar{A}_t\left(\Upsilon_t\right)^{1/\xi-1}(1-\alpha_s)Y_{m,t}^{\xi-1}.$$

Likewise, we have that

$$r_t^{z,s} = q_{s,t}\theta_z Y_{s,t}/Z_{s,t} \quad \text{and} \quad r_t^{z,m} = q_{m,t}\theta_z Y_{m,t}/Z_{m,t}$$

Various no-arbitrage conditions must hold in equilibrium. The marginal product of labor must be the same and equal to the wage rate in all sectors at all times:

$$w_t = q_{s,t}(1-\theta_k-\theta_z)Y_{s,t}/H_{s,t} \quad \text{and} \quad w_t = q_{m,t}(1-\theta_k-\theta_z)Y_{m,t}/H_{m,t}$$

Also, after-tax rates of return on physical (intangible) capital must be equalized across sectors at all times:

$$\widehat{R}_t^k = \widehat{R}_t^{k,s} = \widehat{R}_t^{k,m}, \quad \widehat{R}_t^z = \widehat{R}_t^{z,m} = \widehat{R}_t^{z,s}.$$

Finally, using equilibrium conditions and the government budget constraint, the aggregate feasibility constraint for the economy reads:

$$K_{t+1} + Z_{t+1} + A_{t+1} = (1-\delta_k)K_t + (1-\delta_z)Z_t + Y_t + R^a D_t - C_t - G_t \tag{8}$$

where A_t is the net foreign asset position of the country; it is the aggregate counterpart of a_t in the consumer's budget constraint.

3.2 Discussion

A few comments are now in order in regard to our model economy. We note, as mentioned above, that it is *not* the case that rates of return are necessarily equalized at all times across the three types of assets (physical capital, intangible capital and domestic government bonds). The rate of return on the foreign asset is always R^a. The other rates of return are determined by the following equations, which hold for $t = 0, 1, \ldots$:

$$-u_{c,t} + \beta u_{c,t+1}\widehat{R}_{t+1}^k + \varphi\lambda_t = 0,$$

$$-u_{c,t}q_t + \beta u_{c,t+1} = 0,$$

$$-u_{c,t} + \beta u_{c,t+1}R^a + \lambda_t = 0,$$

$$-u_{c,t} + \beta u_{c,t+1}\widehat{R}_{t+1}^z = 0,$$

where λ_t is the multiplier on the collateral constraint (3). It follows that, if $\varphi \leq 1$,

$$\frac{1}{q_t} = \widehat{R}^z_{t+1} \geq \widehat{R}^k_{t+1} \geq R^a$$

for all $t = 0, 1, \ldots$ so that the rate of return on domestic government bonds and intangible capital may exceed the rate of return on physical capital, which may in turn exceed the rate of return on foreign bonds. On the other hand, if $\varphi \geq 1$, we have

$$\frac{1}{q_t} = \widehat{R}^z_{t+1} \geq R^a \geq \widehat{R}^k_{t+1}$$

so that the world market rate of return may exceed the after-tax rate of return on physical capital. Households accept this because of physical capital's value as collateral against which one may borrow to finance investment in intangible capital.

Second, we note that in the context of an open economy it is natural to define a notion of Gross National Product (GNP)—Gross Domestic Product plus income from net foreign assets. In terms of our notation, GNP is given by

$$GNP_t := Y_t + (R^a - 1)A_t.$$

We use this notion later on to compare the performance of our small open economy in light of data on GNP vs GDP.

4 Parameter Values and Quantitative Exercises

The overall strategy for establishing a benchmark consists in choosing parameters as well as policy instruments in order to match (i) the evolution of Irish tax and government spending policy; (ii) GDP relative to a yearly trend; (iii) the path of GNP to GDP over the period. We fix initial conditions by computing the steady state of a model economy designed to match observations from 1980 and earlier; we then compute the entire path of the model economy until 2005 and beyond.

For computational purposes, as far as the benchmark exercise is concerned, we can think of GDP growth in excess of trend (2 percent per year) as being exogenously given, whereas the path of residual TFP ($\bar{A}_t$) is determined by forcing the model to match the data in

equilibrium. Our GDP target is a smoothed version of the data. It implies that GDP per adult in Ireland should be about 117% higher in 2005 than it would have been had it grown at 2 percent per annum. Similarly, the entire sequence of business tax rates and ratios of government consumption and transfers to output are exogenously given from data. The sequence of labor tax rates is taken from data (see Section 2 and the Online Appendix), except that we add a (possibly negative) surtax that we infer so as to balance the intertemporal government budget. Households correctly anticipate all future changes in policy and technology.

4.1 Parameter Values

Each time period corresponds to one year. We fix initial conditions by computing the steady state of a model economy designed to match observations from 1980 and earlier, and this initial steady state is a necessary input into the computation of the entire path of the model economy until 2005 and beyond. Table 1 presents a summary of our parameter choices with comments in regard to our choices.

Preferences Since, in a steady state, the subjective discount factor β is equal to the reciprocal of the rate of return of net foreign assets, which in turn equals all other after-tax rates of return, we set it so as to reproduce a rate of return of 4 percent in a steady state. The parameter governing the curvature of the disutility of labor, ε, is set to 0.75. This implies a Frisch elasticity of the same value, which lies on the low side of macroeconomic estimates, but far above usual estimates at the individual level.

Technology The physical capital share is assumed to be $1/3$, in line with standard assumptions in the macroeconomic literature. The depreciation rate of physical capital is set to in order to match the average tangible investment to output ratio prior to 1980 (1950-1980), which was about 0.183. The resulting depreciation rate is 0.085. We assume that the rate of depreciation of intangible capital is the same as for tangible capital.

The non-manufacturing share of output, α_s, is set to 0.723 to match the average manufacturing share during the period 1980-2005 which was about 0.277. This share is approximately stable during the period, with an inverted-U shape. From EU KLEMS data,

the manufacturing share was 25.1 percent in the 1980s, increased in the 1990s (average 29.1 percent) and started to declining by the end of the decade, with a value for 2005 of 24.1 percent. The average from 1980 to 2005 was 27.7 percent. Hence, the parameter ξ, determining the elasticity of substitution between manufactures and non-manufactures, is set to zero to generate a constant share of manufactures in output.

The intangible capital share (θ_z) is set in order to reproduce the value of an intangible capital to GNP ratio of 1.7 in the final steady state. This corresponds to the intangible capital to GNP ratio that McGrattan and Prescott (2017) estimate for the United States. The resulting value is $\theta_z = 0.193$. These choices imply a labor share of about 0.474.[9]

Taxes, Government Consumption and Transfers Government purchases G_t and transfer payments $\mathcal{T}_t$ in the initial steady state are such as to match observations in 1980; in subsequent periods, we match the ratios of government consumption and transfers to GDP year by year.[10] Similarly, in the initial steady state, we set the tax rate on corporate income in each sector according to data in 1980; after that, we use the entire sequence of statutory rates from 1980 to 2005.

To calculate the time path of labor tax rates, we use the effective tax rates on labor income and consumption at each date, τ_t^L and τ_t^C, using revenue, income and consumption data from National Income and Expenditure Tables compiled by Ireland's Central Statistics Office (CSO). For labor taxes, we use reported revenues from income taxes, income levies and social insurance taxes. The tax base is the reported overall remuneration of employees plus self-employment income, assuming a share of labor income in self-employment of 2/3. For consumption taxes, we include all revenues from excise taxes plus VAT. The tax base is personal consumption expenditure at market prices.

Using estimates of τ_t^L and τ_t^C, we proceed to calculate the equivalent (empirical) consumption/leisure wedge $\widetilde{\tau}_t$ so that $1 - \widetilde{\tau}_t = (1 - \tau_t^L)/(1 + \tau_t^C)$. Table A1 shows the resulting tax rates, alongside values for government consumption and transfers as a fraction of GDP

[9] This is close to the empirical value. We calculate an average labor share of 0.499 for 1980-2005, and about 0.478 for 1985-2005.

[10] Source: Ireland's Central Statistical Office; Historical, National, Income and Expenditure Tables 1970-1995, Table 5.

(and GNP) and the business tax rates by sector. When we compute transitions to the new steady state, we take as given the observed path of ratios of government consumption and transfers to GDP, the observed time path of business tax rates by sector, and the effective labor tax rates calculated from data. We then determine the model's tax rate on labor income, τ_t, as $\tau_t := \widetilde{\tau}_t + \triangle$, where $\triangle$ is found in order to satisfy the intertemporal budget constraint.

Collateral Constraint and Initial Net Foreign Assets In the initial steady state, the ratio of GNP to GDP is a bit less than one. Specifically, it equals the observed value in 1980 (0.967), according to Ireland's Central Statistics Office. We target this by setting the appropriate value for the initial net foreign asset position A_0. The parameter φ determining the fraction of the physical capital stock that can be used as collateral is set so that the model's long-run value matches the GNP/GDP ratio observed in 2005, which was 0.851.

Summary Given the path for tax rates, government consumption and transfers, and the initial value for net foreign assets, we select the sequence $\bar{A}_t$ and the collateral constraint parameter (φ), in order to reproduce a smoothed version of the empirical growth path for GDP per adult in excess of a 2 percent annual trend and the empirical value of the GNP/GDP ratio in 2005. This implies that GDP per adult in Ireland is about 117% higher than it would have been had it grown at 2 percent per annum. We note that while 2 percent per year is often taken to be a good measure of growth at the frontier, it so happens that a growth rate of 2 percent very closely approximates the performance of output per adult in the United States from 1980 to 2005.

4.2 Ireland: 1980-2005

We now describe the extent to which our model economy conforms with data. Recall that the model is forced to be consistent with the path of output relative to trend. Figure A3 in the Online Appendix shows that the model reproduces the output data very well. Similarly, in Figure 3 we observe the extent to which we match the entire time path of ratio of GNP to GDP. What we see is that the model's implications look like a smoothed version of the data. Thus, our quantitative conclusions are in line with the gradually growing gap

between observed GDP and GNP.

—Figure 3 about here—

Consumption and Hours We now move on to aspects of the Irish economy that we do not explicitly target. We focus on the behavior of consumption and hours worked per adult. First, consider the path of consumption to output (GDP) displayed in Figure A4 in the Online Appendix. Consumption grows over the period 1980-2005, but less than output, leading to a declining path for the consumption/output ratio. Our model is closely in line with this feature of the data as Figure A4 in the Online Appendix demonstrates. Note that a closed economy cannot possibly generate the observed pattern; in a closed economy, the consumption/output ratio *increases* as the economy approaches the steady state from below.

Second, consider the time path of hours worked per adult. Figure 4 shows how the model implications compare to data, when model and data are normalized to 1 in 1985. The figure shows that the model replicates quite well the entire U-shaped path for hours worked per adult, values that are *not* targeted. In anticipation of good things to come—reduction in business taxes, increases in TFP—households reduce their hours initially. This drop in hours is moderated by the gradual increase in labor taxes in the early years; see Table A1. As time goes by and capital flows into the economy from abroad, GNP grows less over time than GDP. This weakens the wealth effect on labor supply (relative to a closed economy), allowing the substitution effect to dominate, leading to a large rise in labor supply in the second part of the period. The predicted rise in hours worked is about 30% from 1985 to 2005, closely in line with the observed increase in hours worked in the data.[11]

—Figure 4 about here—

[11] Relatedly, the model predicts a substantial increase in hourly wage rates over 1980-2005—about 86.1%. This is not too far from the detrended, PPP adjusted value of about 98.1% calculated from the EU KLEMS database. Overall, the success of the model in replicating important features of the data, even those that we do not target, is reassuring. It indicates that the model captures the key factors in the determination of output over time.

Other Dimensions Our model is less successful in other dimensions of the data. First, consider the implications for different rates of return. Recall from our discussion in Section 3.2 that the collateral constraint determines how rates of returns relate to each other. For nearly 15 years after 1980, all assets earn the same after-tax rate of return in the model. From about 1994 onwards, due to the declining business taxes and accelerating TFP growth—see below—a gap opens up between rates of return as the collateral constraint starts to bind. Government bonds and intangible capital earn a maximum premium in 2002 of about 2.4 percentage points over the world market rate, while in 2002, physical capital earns 0.8 percent lower than the world market rate. Subsequently, the premium on government bonds and the discount on physical capital is predicted to gradually decline. In implying a gradual decline in the rate of return on Irish government bonds, the model is qualitatively in line with data; however, Irish bond yields start to decline earlier in the data (early 1990s) than in the model. On this issue, there are clearly considerations we abstract from that were relevant in practice.

Second, while the model reproduces the time path of the GNP to GDP ratio, it does not capture equally well the behavior of the current account. To do that is challenging as short-run capital flows are highly volatile, and the trade balance shows sharp reversals in the data. Nevertheless, our model economy roughly matches the trade balance/GDP ratio towards the end of the sample. According to Irish national accounts, this ratio was about $+0.14$ on average between 2000-2005, which is also the long-run value in the model. What the model does not match is short-run fluctuations in the trade balance. In 1981 it was -13 percent of GDP. It had turned positive by 1985 already and was more than $+10$ percent of GDP in 1995. The model does not replicate this very rapid reversal; instead it implies that the trade balance should be about -10 percent of GDP in 1988-90, and that is should turn positive only towards the end of the period that we study. As in the case of government debt yields, the model gets the overall trends right, but the timing wrong.

Residual TFP Figure 5 displays the residual TFP sequence $\{\bar{A}_t\}_{t=0}^{25}$ that we infer in order to replicate the observed growth rates (above trend) in GDP per adult. Two properties of this sequence are striking. First, the level of TFP is essentially constant until about 1992. Second, the level of TFP is only 24 percent higher in 2005 than in 1980. The first

property is particularly interesting given the dip in GDP per adult in the first 5-6 years, which is connected to the initial fall in hours. The second property is also striking. To put it in perspective, we may ask how much output would go up in the long run as a result of a 24 percent increase in TFP in a standard one-sector growth model without intangible capital and with a capital share of 1/3. The answer, of course, is $1.24^{3/2} \approx 1.38$, implying a mere 38% increase in GDP. If instead, we use the overall capital share assumed here—about 0.53—the long-run increase in output would be about 58%. Clearly this shows that factors other than TFP were important and that a closed economy model is not appropriate for understanding the Irish experience. We evaluate the quantitative importance of these factors, and the importance of openness, below.

—Figure 5 about here—

5 The Quantitative Importance of Fiscal Policy

We now assess the quantitative importance of the policy-driven forces—changes in taxation and government spending—on the performance of the Irish economy, and how those forces interacted with residual TFP changes. We do this by considering each of these forces in isolation, and also by dropping each factor one by one, assuming that it stayed the same from 1980 to 2005. In doing so, we provide our model estimates of the contribution of changes in fiscal policy to the Irish miracle.

5.1 Changes in Taxation

What is the contribution of the gradual reduction in business taxes to the Irish miracle? The answer is shown in Figure 6. It shows what would have happened, according to our model, if observed business tax reform were the *only* exogenous change that took place during the relevant period. Table 2 summarizes the predicted effects of the tax reform in isolation on output, hours worked and the GNP/GDP ratio.

—Figure 6 about here—

Our findings indicate that tax reform would have led, in itself, to a sizeable change in output by 2005; about 23 percent. However, this effect is less than a fifth of the overall changes in output as predicted by the model. Put differently, despite the amplifying effects of intangible capital in the context of an open economy, the consequences of tax reforms on output are a mere fraction of the observed effects.

Harmonization Recall that the Irish reform of business taxes involved not only a reduction, but an equalization of rates across sectors, thus reducing not only a distortion affecting the overall size of the capital stock, but eliminating an intersectoral distortion as well. To quantify the importance of this channel, we first calculate the sector-weighted tax rate in 1980. We then compute the gradual changes in tax rates that would ensue if intersectoral tax rate gap were to shrink as in the data—and vanish by 2003—but assuming a time-invariant sector-weighted average tax rate. If harmonization were the only factor changing from 1980 onwards, our model tells us that output would increase by just 2.5% from 1980 to 2005. This is much lower than the predicted increase in output when the full business tax reform is in place. Hence, the overall *reduction* in corporate rates is the critical driving factor behind the effects of business tax reform, not harmonization.

Changes in Labor Distortions As described in section 2, there were changes in labor taxes (τ) over the period 1980-2005 which are shown in Table A1 in the Online Appendix. The value for τ rose from 35.7% in 1980 until the late eighties and then remained approximately constant at about 43-44%. What are the consequences if changing labor wedges were the only driving force during the period? Not surprisingly, we find that rising labor income taxes impede long-run growth. As households anticipate higher taxes in the future, they work relatively more early on, causing a gradual subsequent decline in labor supply and output. The decline in output by 2005 is about one percent. Alternatively, we can ask what would happen if all the driving forces are as in the benchmark, except labor tax rates, which are forced to be *time invariant* (but consistent with the intertemporal budget constraint). What we find in this case is that output would have grown by 1.4 percentage points more by 2005 relative to the benchmark case. In sum, we find that changing labor taxes were an impediment to growth; however, their quantitative effects had a small contribution to the Irish Miracle.

5.2 All Together Now

We now examine the effects of all changes in fiscal policy. That is, business tax reform, changes in labor taxes as well as changes in government consumption and transfers in the context of our model economy, assuming that TFP had remained on trend. Recall from our discussion in Section 2 that the consumption/leisure distortion increased until the late eighties. Meanwhile, transfers remained constant as a fraction of output, while government consumption declined.

Figure 7 and Table 2 describe the predicted effects associated with all changes in fiscal policy. In this hypothetical case, the overall increase in output per adult is about 27%. In itself, the reduction in government size leads to a reduction in distortionary labor taxes, which in turn leads to an increase in labor supply, and corresponding increases in the marginal products of capital and capital inflows. These effects are tempered by the increases in labor distortions, and interact with the consequences of business tax reform. Overall, the effects of all fiscal policy changes can be viewed as substantial, with the bulk of these effects driven by business tax reform. Changes in fiscal policy alone would have led to a level of output per adult of about 62% of the U.S. by the year 2005. This change amounts to less than a third of the observed changes in relative output that took place.

—Figure 7 about here—

5.3 The Role of Productivity Changes

What, apart from fiscal policy, accounts for the observed changes in output in the period 1980-2005? Put differently, what was the contribution of changes in TFP to output during this period? Figure 7 and Table 2 illustrate what would have happened if the increase in TFP were the only exogenous change that took place during the relevant period. Our results show that changes in TFP in itself are a major factor in accounting for the Irish miracle. TFP alone would have led to an output increase above trend of about 76 percent by 2005 relative to 1980. This represents about 65 percent of the change in output as predicted by the model. Thus, our model implies an important role for residual changes in TFP, above and beyond the changes in taxation and government spending.

In summary, three points are central from our findings so far. First, our model economy predicts large effects from business tax reform, but these effects account for only a fraction of the output changes observed in Ireland. This is true despite capital movements, the amplifying effects of intangible capital and endogenous labor supply. Second, the inferred changes in residual TFP appear central in accounting for the Irish miracle. Whatever these increases in productivity represent, they are essential; without them, the model predicts increases in output that are only about a third of the actual ones.

Finally, the changes in the various driving forces reinforce each other in significant ways. Note that the sum of the changes in output implied by fiscal policy and TFP individually ($27 + 76$ percent) is non-trivially smaller than the overall change in the long run. These changes in isolation account for about 88 percent of the total changes in output predicted by the model. Intuitively, it is not hard to imagine why this is the case. The effects of a gradual tax reform that increases the after-tax marginal product of both types of capital are magnified by a rising TFP, and vice versa.

5.4 Anticipation Effects

How important is it that the changes in exogenous driving forces—business tax rates, labor tax rates, government expenditures and residual TFP—are perfectly foreseen? To answer this question, we consider the implications of a particularly severe case of imperfect foresight. What we assume is that each change in the exogenous variables is a complete surprise but is expected to be permanent. The resulting transition is then computed as a sequence constructed from the initial periods of a sequence of transitions, each of which is based on the assumption that (i) initial values of state variables are as inherited by the previous transition and (ii) the initial period values of the exogenous variables are as in the benchmark and are expected to remain at those levels *forever*. In this context, after each "surprise" and under the assumption that changes are permanent, we recompute the labor income surtax that balances the intertemporal budget constraint. We refer to the transitional dynamics that ensue under these assumptions as the case of *static beliefs*. Because of the extreme myopia implied by the approach we adopt here, we regard it as maximizing the potential role of expectations; any other reasonable approach is likely to

take us closer to the perfect foresight outcome.[12]

The main result of our exercise is presented in Figure A5 in the Online Appendix, where output under the benchmark and the static beliefs are displayed. We find that under static beliefs, output initially increases whereas output in the benchmark case slightly declines. The gap between the two cases eventually vanishes around 1995. After 1995 output under static beliefs grows less than in the benchmark case. In 2005, output under static beliefs is about 87% of the benchmark.

What accounts for the differences between the benchmark case and the case of static beliefs? In the benchmark, anticipation of very good things to come (a tax reform, increases in TFP) implies that the early years of the transition are not good times to work (but a good time to consume), leading to borrowing from abroad and a growing gap between GDP and GNP. This anticipation of good things to come is tempered by the fully anticipated increase in labor tax distortions up to the late eighties. In net terms, hours and output drop early on and given data, a slight boost in TFP is required in order to prevent an even deeper dip in GDP than we observe right after 1980. Under static beliefs, the anticipation effect is absent, and we observe an early increase in output. As time goes by, good times finally arrive and output starts growing faster under the benchmark case.

In sum, given that our static belief case involves an *extreme* form of myopia and that output levels around 2005 are not too different under the same driving forces, we conclude that the importance of anticipation effects is limited. However, and not surprisingly, myopia associated with future changes in policy can lead to noticeably different paths for key variables for our analysis, such as output and labor supply.

6 Results in Perspective

In this section, we attempt to put our results in perspective. We evaluate the quantitative importance of openness to capital inflows for our findings, and discuss potential sources for the inferred growth of TFP. See the Online Appendix for further perspectives on our results.

[12]This approach we use is similar to that of Auray et al. (2017). We thank P. Gomme for the suggestion.

6.1 The Role of Openness

Is it important to study the Irish experience from the standpoint of an open economy? Did openness matter? To answer this question, we start by examining what would have happened if Ireland had been closed to foreign investment. Specifically, we take all the driving forces in our baseline exercise for the period 1980-2005, and compute the corresponding transition path. As seen in Figure 8, the increase in GDP would have been dramatically smaller, only 53% by the end of the period or *less than half* of the benchmark output changes. If we specifically focus on the role of business tax reform, the consequences are also sharply different from the equivalent exercise in our (open economy) benchmark. In this (closed economy) case, output (GDP) is predicted to increase by only about 11% from 1980 to 2005 (as opposed to 23% in the open economy benchmark). From this analysis, we conclude that considering the Irish miracle in the context of an open economy is essential.

—Figure 8 about here—

What accounts for the differences in the behavior of a small open economy versus more closed ones? The main reason is due to the delay in growth that closedness implies. Foreign investment obviously speeds up the process of convergence to a new balanced growth path, resulting in a growing gap between GDP and GNP. If the economy is closed, our model implies that GDP would eventually settle at about 87 percent above trend in a new steady state. Thus, our model predicts a substantial role for openness not only in accelerating convergence to a new balanced-growth path but in determining the level of that path.

The long-run level difference is perhaps the most important one, because it comes from the large implied long-run rise in labor supply that takes place in an open economy, but not in a closed one, even one for which the TFP sequence were chosen to match the evolution of GDP. The benchmark exercise implies a 15.4 percent increase in labor supply by 2005, whereas the hours increase is only 1.5 percent in the closed economy model. The reason for this difference is the following. In the open economy, the growing gap

between GDP and GNP implies that domestic wealth increases less than wage rates do. Thus, even under preferences consistent with a balanced growth path, income and substitution effects do not cancel out.

Different Degrees of Openness We also explore the effects of different degrees of openness, by varying the tightness of the collateral constraint (φ). In doing so, we implicitly change how 'elastic' capital inflows are to changes in after-tax rates of return and thus, how inflows affect output. If the economy is not fully open ($\varphi = 1/2$ the benchmark value), the increase in output is much lower than in the benchmark—only 70% by 2005—while missing the observed increases in labor supply after 1985. A full analysis is in the Online Appendix, where we find non-linear effects on output as φ varies.

6.2 Potential Sources of TFP Growth

Since the rise in TFP from the standpoint of the model is key in understanding the Irish miracle, we elaborate on some potential sources for this rise. We focus on three of them below.

Changes in Labor Quality There were, arguably, changes in the skills embodied in Irish workers that we did not incorporate in our benchmark analysis, or *labor quality* for short, that could reduce the magnitude of inferred TFP changes. We calculate that years of schooling in Ireland went up by about two years on average; from around 9.9 in 1980 to about 11.9 years in 2005. In the Online Appendix, we investigate the importance of these increases in labor quality as measured by years of education in the context of our framework. We find that when all driving forces are considered, accounting for changes in labor quality reduces the required TFP increase from about 27% in the benchmark case to about 19%.

Migration In our analysis, we have focused on output per adult, avoiding consideration of demographic changes. One source of such change was a rise in net migration. In Ireland, net migration went from being negative (and substantial in the eighties) to positive by 1996 and onwards. Net migration (as a percentage of the population) reached a

minimum of -1.2% in 1989, and then increased gradually to $+1.3\%$ by 2005.[13] Overall, the contribution of net migration to Irish population growth was minuscule; while population growth was about 0.78% per year from 1980 to 2005, we calculate that population growth in the absence of migration would have been very similar: 0.71%. Nevertheless, net migration may have contributed to the sizeable increase in the fraction of working-age adults in the population, though a large fall in fertility was probably more important in that context.

In any case, we are skeptical that migration into Ireland could have been an important factor in the Irish miracle. First, we found in Klein and Ventura (2009) that in an open-economy growth model with a fixed factor, labor inflows generically lead to a reduction in output per worker, even in the long run, though these reductions are small under an empirically plausible share of the fixed factor in production. Second, to have noticeable effects on output per head, labor inflows have to increase quite significantly the average skill level of the labor force. Given the relatively low values of net migration over the period, we conclude that this is far from plausible. It is best to view the more recent migration experience in Ireland as a consequence of the output miracle, not a cause.

Deepening of EU Integration The Single European Act, signed in 1986 and fully implemented by the end of 1992, deepened economic integration within the EU. It fully established the "four freedoms"—freedom of movement for goods, services, capital and workers. In particular, the act eliminated differences in technical (e.g. health and safety) standards from constituting barriers to trade in goods. This was accomplished via a combination of mutual recognition (e.g. goods meeting Irish standards may be sold in Germany) and harmonization (common standards for the EU as a whole). Even where regulatory divergence did not in fact exist previously, the new legal order removed the need for costly documentation that a good in fact met national standards in the destination country. In addition, it removed barriers to trade in services. As a result, a German firm could provide insurance services in Ireland and vice versa; similarly a British or Spanish bank could set up branches in Ireland.

[13] Source: Ireland's Central Statistics Office, https://www.cso.ie.

It is not hard to imagine that these changes in the European context could have contributed significantly to the Irish miracle, and complemented the business tax reform already going on. Indeed, we infer—see Figure 5—that the bulk of TFP increases as predicted by the model occur after 1992. Further work should determine the quantitative impact of this channel, and if quantitatively important, why it it did not have comparable effects in similarly situated countries.

7 Concluding Remarks

We conclude the paper with two comments. The first one pertains to the behavior of labor supply in the period of analysis. Our framework replicates, qualitatively and quantitatively, the observed U-shaped pattern of hours worked per adult over time. On this point, as we noted in Section 2, the changes in hours per adult were accompanied by large increases in the number of adults engaged in the labor market. Notably, this increase in employment rates took place strongly for a key group, namely married women, mirroring a trend in several other countries. Since changes in labor supply can arguably be crucial for understanding changes in output per capita, future work should investigate miracle episodes like Ireland's in the context of deeper models of labor supply that consider both the intensive and the extensive margin in the context of multi-member households. [14]

The second point concerns our finding that changes in aggregate TFP are the primary drivers of output changes in the Irish miracle. This holds even when our model includes intangible capital whose presence tends to amplify the effects of fiscal policy, especially in an open-economy context. Future work should shed light on the deeper reasons for these changes in TFP. An additional interpretation of these TFP changes is related to the forces associated with multinational production and its reallocation across borders, emphasized by Burstein and Monge-Naranjo (2009), Ramondo and Rodríguez-Clare (2013) and many others. From this perspective, changes in openness to multinational firms would act as changes in TFP. However, such a line of argument, as we argued in Section 6, needs to allow for the fact that other EU (and EEA) countries operated under the same regulatory

[14] See Cubas (2016) for a recent analysis of the interplay between changes in female labor supply and development in Latin American countries.

framework. Meanwhile, we conjecture that changes in labor market regulation and labor practices in Ireland may have had substantial effects that were amplified in an open economy context. We leave these and other potential factors that could rationalize the inferred changes in TFP for future work.

References

Ahearne, A., F. Kydland, and M. A. Wynne (2006). Ireland's Great Depression. *The Economic and Social Review 37*(2), 215–243.

Auray, S., A. Eyquem, and P. Gomme (2017). Debt hangover in the aftermath of the Great Recession. Working Paper Series 17-003, Concordia University.

Barro, R. J., N. G. Mankiw, and X. Sala-i Martin (1995). Capital mobility in neoclassical models of growth. *American Economic Review 85*(1), 103–115.

Barry, F. and M. B. Devereux (2006). A Theoretical Growth Model for Ireland. *The Economic and Social Review 37*(2), 245–262.

Blanchard, O. (2002). Comment on Walsh and Honohan. *Brookings Papers on Economic Activity 33*(1), 58–77.

Burstein, A. T. and A. Monge-Naranjo (2009). Foreign Know-How, Firm Control, and the Income of Developing Countries. *The Quarterly Journal of Economics 124*(1), 149–195.

Central Statistics Office, Ireland (2011). Foreign Direct Investment 2011. Available at http://www.cso.ie/en/statistics/balanceofpayments/archive/releasearchive2011/.

Cooley, T. F. and L. E. Ohanian (1997, June). Postwar British Economic Growth and the Legacy of Keynes. *Journal of Political Economy 105*(3), 439–472.

Corrado, C., C. R. Hulten, and D. E. Sichel (2006). Intangible capital and economic growth. Finance and Economics Discussion Series 2006-24, Board of Governors of the Federal Reserve System (U.S.).

Correia, I. H. (1996). Dynamic optimal taxation in small open economies. *Journal of Economic Dynamics and Control 20*, 691–708.

Crucini, M. J. and J. Kahn (1996, December). Tariffs and aggregate economic activity: Lessons from the Great Depression. *Journal of Monetary Economics 38*(3), 427–467.

Cubas, G. (2016). Distortions, infrastructure, and female labor supply in developing countries. *European Economic Review 87*(C), 194–215.

Gross, T., P. Klein, and M. Makris (2019). Residence- and source-based capital taxation in open economies with infinitely-lived consumers. Manuscript.

Hall, R. E. (2001, December). The Stock Market and Capital Accumulation. *American Economic Review 91*(5), 1185–1202.

Honohan, P. and B. Walsh (2002). Catching up with the leaders: The Irish hare. *Brookings Papers on Economic Activity 33*(1), 1–78.

Kapicka, M. (2012, April). How Important Is Technology Capital for the United States? *American Economic Journal: Macroeconomics 4*(2), 218–248.

Klein, P. and G. Ventura (2009). Productivity differences and the dynamic effects of labour movements. *Journal of Monetary Economics 56*(8), 1059–1073.

McGrattan, E. R. and L. E. Ohanian (2010, May). Does Neoclassical Theory Account For The Effects Of Big Fiscal Shocks? Evidence From World War II. *International Economic Review 51*(2), 509–532.

McGrattan, E. R. and E. C. Prescott (2010). Unmeasured investment and the puzzling U.S. boom in the 1990s. *American Economic Journal: Macroeconomics 2*, 88–123.

McGrattan, E. R. and E. C. Prescott (2017, March). On financing retirement with an aging population. *Quantitative Economics 8*(1), 75–115.

Ohanian, L. E. (1997, March). The Macroeconomic Effects of War Finance in the United States: World War II and the Korean War. *American Economic Review 87*(1), 23–40.

Ramondo, N. and A. Rodríguez-Clare (2013). Trade, Multinational Production, and the Gains from Openness. *Journal of Political Economy 121*(2), 273–322.

Tørsløv, T. R., L. S. Wier, and G. Zucman (2018). The missing profits of nations. NBER Working Papers 24701.

World Bank (2017). World development indicators.

Table 1: Parameter Values

Parameter	Description	Value	Comments
	Parameters Set Exogenously		
β	Discount Factor $(1/R^a)$	$1/1.04$	Implies $R^a - 1 = 4\%$.
θ_k	Share of Physical Capital	$1/3$	Literature.
ε	Frisch Elasticity	0.75	Literature.
	Parameters Set Endogenously		
θ_z	Share of Intangible Capital	0.193	Matches long-run $Z/GNP = 1.7$.
δ_k	Tangible Depreciation Rate	0.086	Matches $I_k/Y = 0.183$ pre 1980.
δ_z	Intangible Depreciation Rate	0.086	$\delta_z = \delta_k$.
α_s	Non-manufacturing Share	0.723	Matches empirical shares.
$1/(1-\xi)$	Substitution Elasticity Manufacturing vs Non-manufacturing	1.0	Implies Constant sectoral shares.
φ	Collateral Constraint	1.350	Matches GNP/GDP in 2005.
$\triangle$	Additional Labor Tax	- 0.022	Balances Intertemporal Budget Constraint
	Exogenous Data Values		
τ^m_{1980}	Manufacturing Tax Rate	0.10	Data.
τ^s_{1980}	Non-Manufacturing Tax Rate	0.50	Data.
τ^m_{2005}	Manufacturing Tax Rate	0.125	Data.
τ^s_{1980}	Non-Manufacturing Tax Rate	0.125	Data.
τ_{1980}	Labor Tax Rate in 1980	0.357	Data.
τ_{2005}	Labor Tax Rate in 2005	0.437	Data.
$(G/Y)_{1980}$	Gov't consumption/GDP 1980	0.198	Data.
$(G/Y)_{2005}$	Gov't consumption/GDP 2005	0.142	Data.
$(\mathcal{T}/Y)_{1980}$	Transfers/GDP 1980	0.091	Data.
$(\mathcal{T}/Y)_{2005}$	Transfers/GDP 2005	0.094	Data.

Note: This table summarizes the parameter values used in the analysis. The top panel contains parameters set exogenously. The central panel contains parameters chosen to reproduce observations. The bottom panel shows initial values and final values for tax rates on business and labor income. See Section 1 in the text and Table A1 in the Online Appendix for details .

Table 2: Implications of hypothetical scenarios

	1980	1985	1990	1995	2000	2005
Tax reform only						
GDP	1.000	0.905	0.966	1.028	1.170	1.230
Hours	1.000	0.905	0.919	0.949	1.009	1.020
GNP/GDP	0.967	0.978	0.953	0.942	0.920	0.915
Fiscal policy reform only						
GDP	1.000	0.931	0.997	1.060	1.204	1.269
Hours	1.000	0.931	0.949	0.978	1.039	1.053
GNP/GDP	0.967	0.964	0.933	0.918	0.896	0.892
TFP changes only						
GDP	1.000	0.983	1.001	1.183	1.423	1.756
Hours	1.000	0.920	0.917	0.989	1.068	1.125
GNP/GDP	0.967	0.945	0.916	0.885	0.875	0.874
Data						
GDP	1.000	0.909	1.119	1.287	1.728	2.121
Hours	1.000	0.875	0.929	0.993	1.129	1.148
GNP/GDP	0.967	0.897	0.887	0.886	0.854	0.851

Note: This table shows the behavior of GDP, hours worked and the GNP/GDP ratio over time in different cases. The first panel shows the case of a business tax reform in isolation. The second panel shows the case of only fiscal policy changes—tax reform, changes in labor taxes and changes in government expenditure. The third panel shows the case of changes in residual TFP only. For comparison purposes, the last panel presents the corresponding values from data.

Figure 1. Ireland's GDP Per Adult and Business Tax Rates.

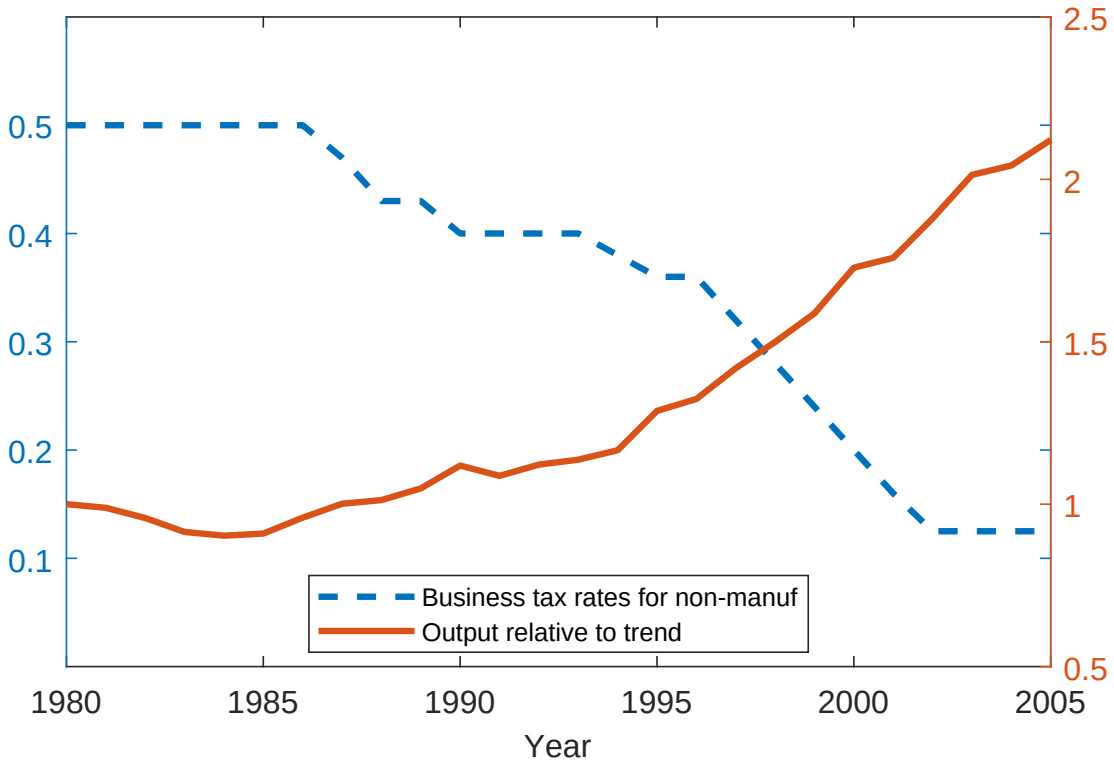
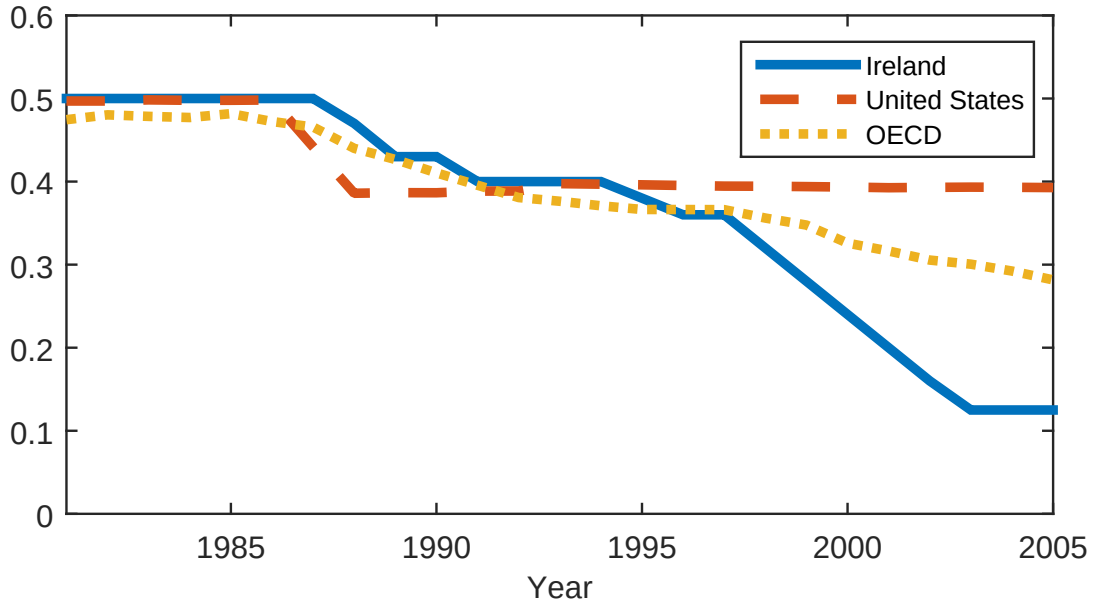


Figure 2. Statutory Business Tax Rates: Ireland, U.S. and the OECD.



Source: http://taxfoundation.org/article/oecd-corporate-income-tax-rates-1981-2013.
The numbers for the OECD are a GDP-weighted average.

Figure 3. GNP/GDP ratio: Model vs Data

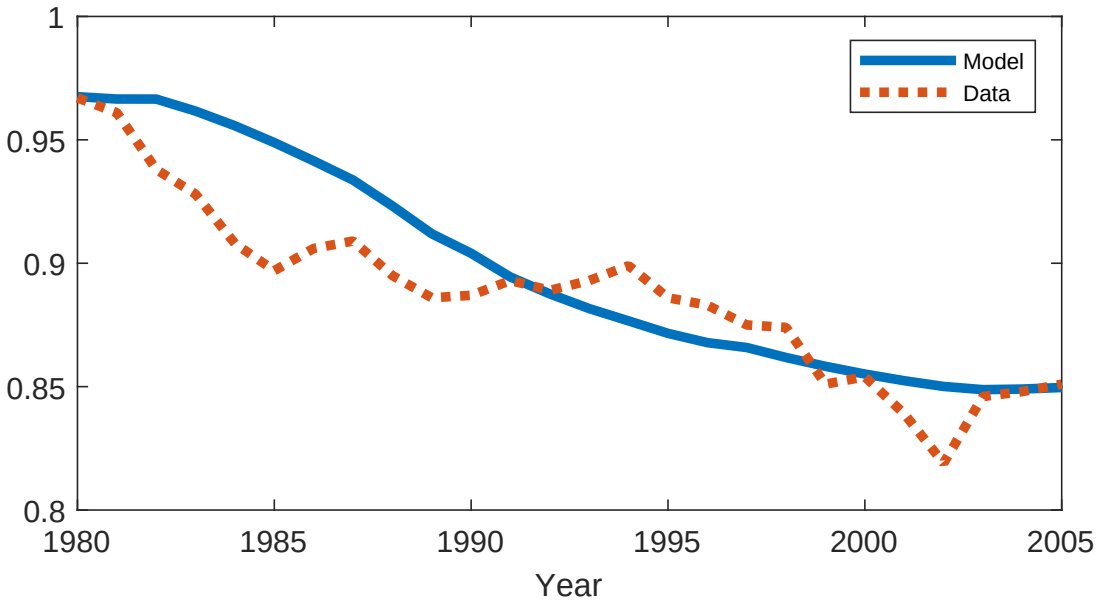


Figure 4. Hours Worked Per Adult: Model vs Data (1985=1)

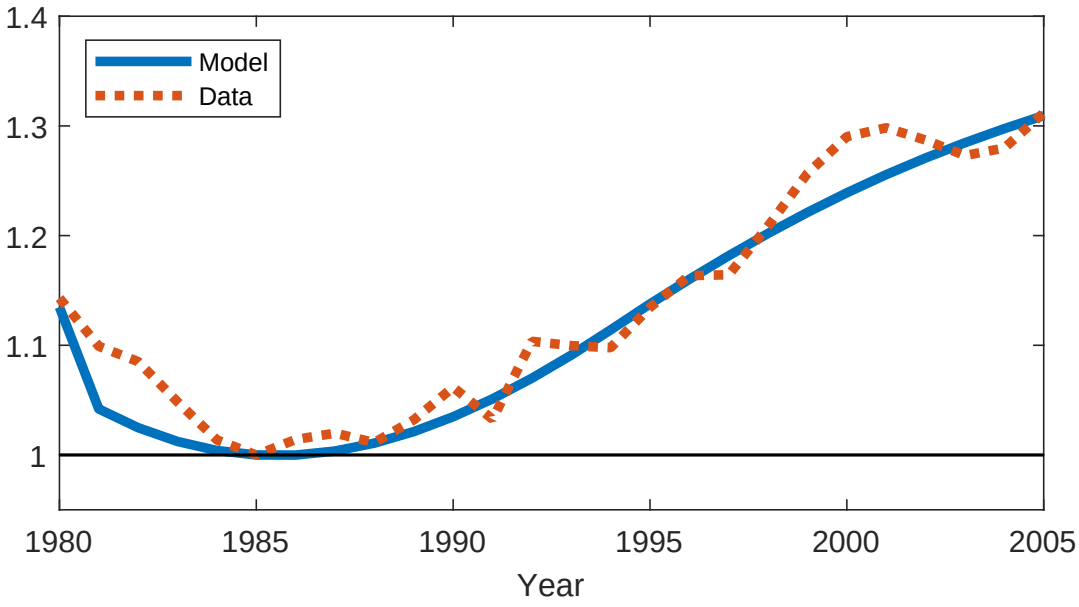


Figure 5. Inferred TFP Values

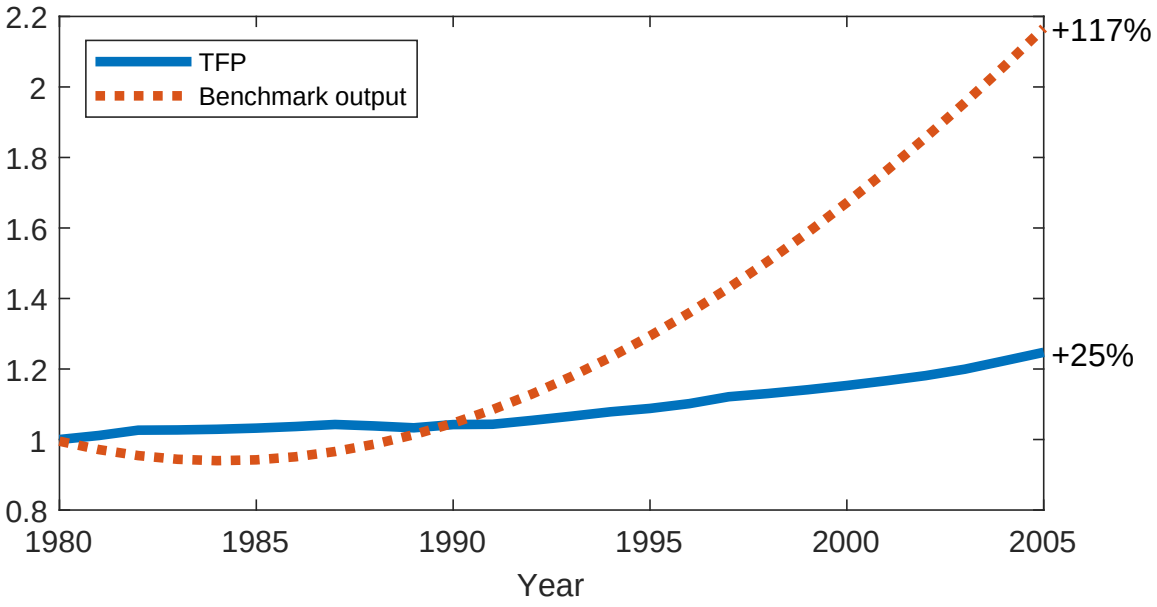


Figure 6. Output per adult: Tax Reform Only

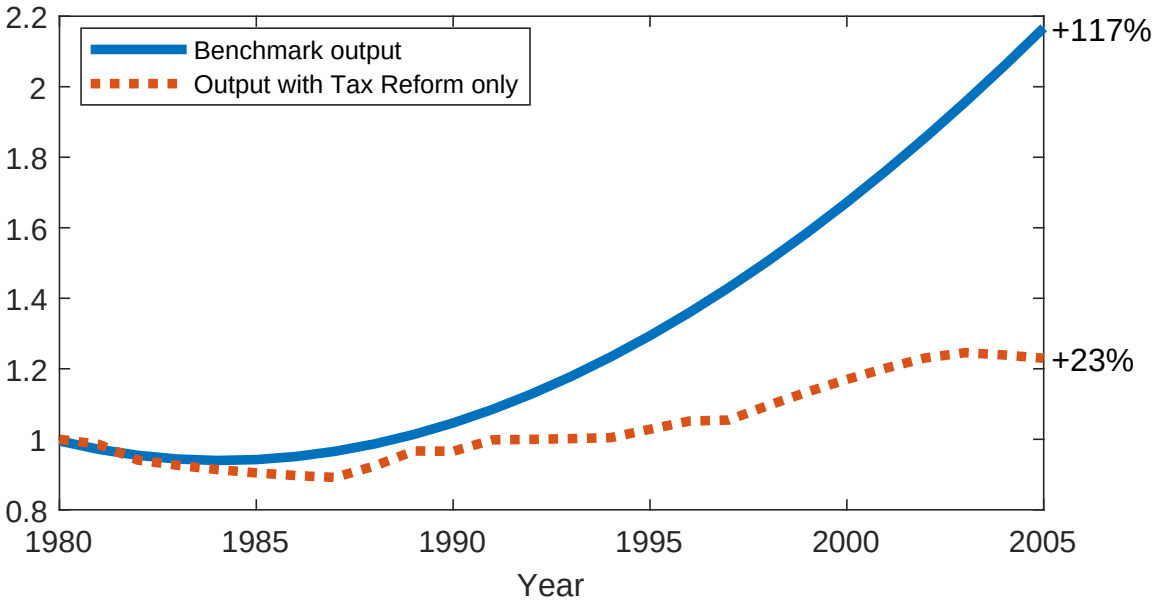


Figure 7. Output per adult: Only Fiscal Policy Changes and Only TFP Changes

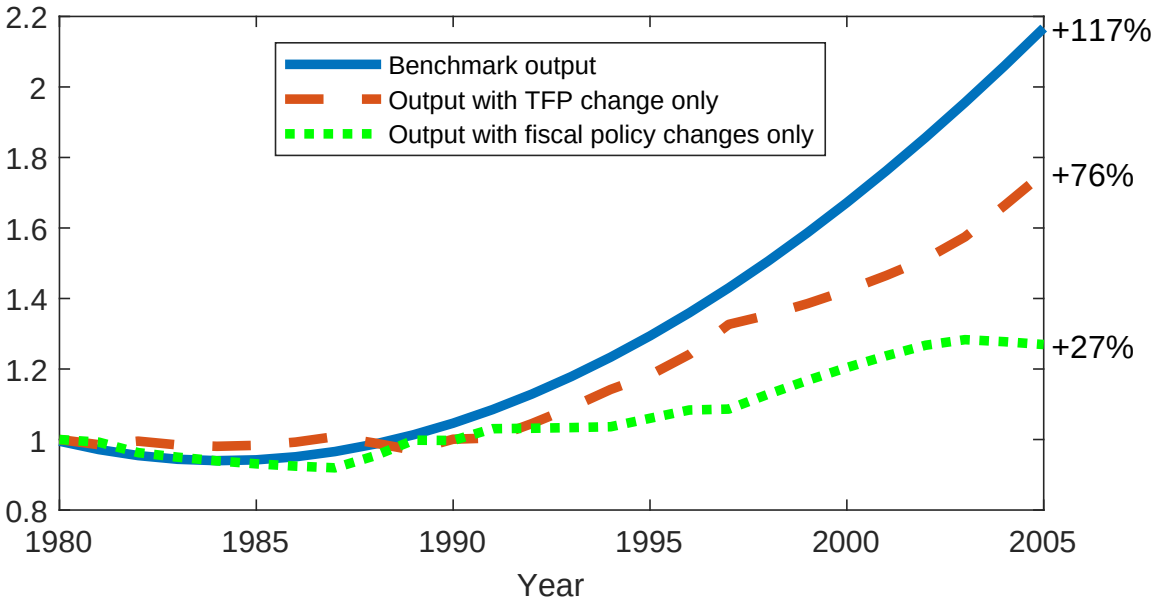
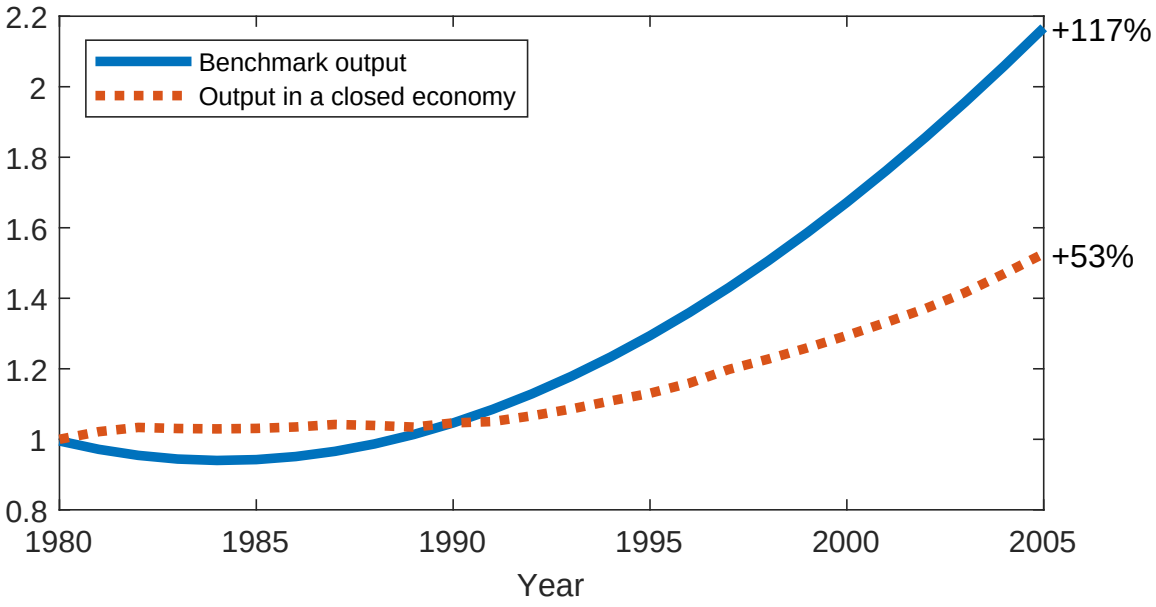


Figure 8. Output per adult: closed vs open economy



Taxation, Expenditures and the Irish Miracle: Online Appendix

Paul Klein and Gustavo Ventura

A1 Fiscal Policy in Ireland

Table A1: Fiscal Policy in Ireland, 1980-2005

Year	G/GDP	T/GDP	G/GNP	T/GNP	τ^m	τ^s	τ^L	τ^C	$\tilde{\tau}$
1980	0.198	0.091	0.205	0.094	0.100	0.500	0.219	0.214	0.357
1981	0.199	0.098	0.207	0.102	0.100	0.500	0.228	0.232	0.373
1982	0.196	0.112	0.209	0.120	0.100	0.500	0.246	0.262	0.403
1983	0.193	0.118	0.208	0.127	0.100	0.500	0.259	0.275	0.419
1984	0.188	0.117	0.207	0.128	0.100	0.500	0.277	0.279	0.435
1985	0.187	0.119	0.209	0.133	0.100	0.500	0.280	0.267	0.431
1986	0.190	0.121	0.209	0.134	0.100	0.500	0.294	0.263	0.441
1987	0.181	0.118	0.199	0.130	0.100	0.500	0.307	0.253	0.447
1988	0.168	0.114	0.187	0.128	0.100	0.470	0.319	0.263	0.461
1989	0.158	0.102	0.178	0.115	0.100	0.430	0.290	0.267	0.439
1990	0.161	0.099	0.182	0.111	0.100	0.430	0.291	0.254	0.434
1991	0.170	0.104	0.190	0.116	0.100	0.400	0.295	0.241	0.432
1992	0.173	0.107	0.195	0.120	0.100	0.400	0.291	0.242	0.429
1993	0.172	0.106	0.192	0.119	0.100	0.400	0.295	0.232	0.428
1994	0.170	0.105	0.189	0.117	0.100	0.400	0.298	0.253	0.440
1995	0.159	0.098	0.180	0.111	0.100	0.380	0.275	0.275	0.432
1996	0.153	0.097	0.173	0.110	0.100	0.360	0.274	0.276	0.431
1997	0.148	0.087	0.169	0.099	0.100	0.360	0.279	0.287	0.439
1998	0.140	0.079	0.161	0.091	0.100	0.320	0.276	0.294	0.440
1999	0.136	0.069	0.159	0.081	0.100	0.280	0.281	0.297	0.446
2000	0.133	0.063	0.155	0.074	0.100	0.240	0.285	0.300	0.450
2001	0.139	0.066	0.166	0.079	0.100	0.200	0.270	0.271	0.426
2002	0.142	0.074	0.173	0.090	0.100	0.160	0.273	0.280	0.432
2003	0.143	0.075	0.169	0.088	0.125	0.125	0.264	0.277	0.424
2004	0.144	0.075	0.169	0.089	0.125	0.125	0.278	0.292	0.441
2005	0.142	0.094	0.167	0.111	0.125	0.125	0.269	0.299	0.437

*Note: This table summarizes key variables of fiscal policy in Ireland for the years 1985-2005 for the purposes of this paper. The first two columns display the ratios of Government Consumption and Transfers to GDP (*G/GDP *and* T/GDP*, respectively). The next two show the corresponding ratios as a fraction of GNP. The next two columns display the corporate tax rates for the manufacturing sector (τ^m) and non-manufacturing sector (τ^s). The next two columns display the tax rates for labor income (τ^L) and consumption (τ^C). The last column shows the implicit tax rate on labor ($\tilde{\tau}$) based on labor and consumption tax rates. See Section 4 in the main text for details.*

A2 Computation

Every transition path is solved for in the following conceptually straightforward way. Notice that the long-run allocation depends on initial conditions; we do not "close" the model à la Schmitt-Grohé and Uribe (2003).

We fix a time horizon T after which we conjecture that the economy has come very close to the long-run allocation. We then stack the equilibrium conditions up from period 0 until period T and force variables at time periods T and $T+1$ to equal each other.[1] An approximate solution to the resulting system of equations is then found by using Broyden's (1965) method. Notice that this approach does not require that we compute the long-run steady state in advance of computing the transition; rather than insist on convergence to a known steady state, we insist on convergence to *some* steady state.

Notice also that some of our conditions are inequalities; they are enforced using a complementarity method. Specifically, we enforce the conditions $a_{t+1} + \varphi k_{t+t} \geq 0$ and $\lambda_t \geq 0$, with equality in at least one of these two cases, by insisting that

$$\min(\lambda_t, b_{t+1} + \varphi k_{t+t}) = 0$$

for all t.

[1] The method is known in the literature as the *extended path* method and was first described in Fair and Taylor (1983).

A3 Different Degrees of Openness

In section 6.1 of the main text, we compared the quantitative effects of the all the driving forces (fiscal policy, productivity changes) in a closed economy versus our benchmark, and explained the differences between the two polar cases. We focus now with higher resolution on intermediate, different degrees of openness, by varying the parameter φ that governs the tightness of the collateral constraint. In doing so, we implicitly change how elastic capital inflows are to changes in after-tax rates of return and thus, how inflows of foreign capital affect output and other variables.

In Table A2, we present results for four different cases of openness expressed as multiples of the benchmark value, φ^*. For comparison, we present in the table the cases of a fully closed economy $\varphi^* = 0$ and the benchmark economy.

Note than when the tightness parameter is equal to half the benchmark value, all the driving forces lead to changes in output of about 70% by 2005—about 60% the observed value – and a value of the GNP-GDP ratio of 93.6%—significantly higher than the observed one that we target. In this case, the predicted increase in hours worked by 2005 is only 4.8%, far from the empirical value of 14.8%. Note that the benchmark economy predicts an increase in hours by 2005 in the same ballpark of 15%, capturing the entire time path for hours for the 1980-2005 period, *without* targeting the behavior of hours at all. Similar considerations apply to even higher (less tight) values of φ, strongly suggesting that in the context of our framework, considering a (frictional) open economy matched to data on GNP to GDP ratios is key to assess the Irish experience. As we discuss below, this is also key to assess the welfare implications of the changes observed in this period. Overall, these consistency with multiple observations provide us with confidence that we capture well how elastic capital inflows are to changes in after-tax rates of return.

More broadly, our findings show a logistic-shaped relationship between output changes (hours) and the tightness of the collateral constraint. Relaxing the constraint somewhat from the closed economy to $\varphi^* = 1/3$ does not lead to quantitatively significant effects. But as φ increases further, output and labor start growing much faster. This indicates that for generating large output and labor supply changes, relatively 'small' departures from

a closed economy do not generate large effects; sufficiently large departures are needed. Moreover, further degrees of openness have stronger effects, suggesting high output costs from reductions in openness in a fairly open economy like Ireland.

Table A2: Different Degrees of Openness (%)

Statistic	$\varphi = 0$	$\varphi = 1/3\varphi*$	$\varphi = 1/2\varphi*$	$\varphi = 2/3\varphi*$	$\varphi = 3/4\varphi*$	$\varphi = \varphi*$
Output Change (1980-2005)	52.7	60.8	70.1	82.2	89.9	116.7
Hours Change (1980-2005)	1.5	3.0	4.8	7.3	9.0	15.4
GNP/GDP (2005)	0	96.0	93.6	90.9	89.5	85.1

Note: This table presents the effects on output (GDP) and hours worked changes over 1980-2005, in conjunction with the values of GNP to GDP by 2005, of all the driving forces under different scenarios for the parameter defining the severity of the collateral constraint. The first column is our closed economy case ($\varphi = 0$). The last column is the benchmark case, with the parameter at its calibrated value ($\varphi = \varphi^*$). The intermediate cases show a gradual relaxation of the collateral restriction, with φ as different fractions of the benchmark value. See the text for details.

A4 Robustness

A4.1 The Role of Labor Supply

What is the quantitative importance of changes in hours of work, and labor supply more broadly, for our analysis and conclusions? We answer this question in two ways. We first evaluate the model implications that ensue when labor supply elasticities are different than in the benchmark case. Second, we evaluate the potential importance of changes in labor efficiency units as a driving force for the Irish miracle.

Labor Supply Elasticities Recall that in our benchmark parameterization model, the labor supply elasticity (ϵ) takes a value of 0.75. This value is higher than most estimates for prime working-age males, but on the low side of macroeconomic estimates. Recall also that in the benchmark case, our benchmark economy is consistent with the behavior of hours worked over time displayed in Figure 4 in the main text—values that are *not* targeted. Since labor supply changes are large in the period, we now ask how sensitive are our results to our choice of this critical parameter.

We start by examining the case in which the labor supply elasticity is much lower: ($\epsilon = 0.25$). For this case, we recalibrate the model following the procedure outlined in Section 4 in the main text. In this case, the model yields an increase in residual TFP for the 1980-2005 period that is larger than in the benchmark case—29.3 versus 24.7 percent. In this case, unlike the benchmark case, the model does *not* match well the increase in hours by 2005: while the benchmark model predicts an increase closely aligned with data (about 15%), the model with $\epsilon = 0.25$ predicts an increase of only 6.9%. In any case, for the special case of tax reform *only*, our results indicate that the effects on output decline as the elasticity is reduced, but not by much. The increase in output by 2005 is 23.0 percent in our benchmark case, while the increase is 21.1 percent under the low elasticity value ($\epsilon = 0.25$).

We can also examine what would be the consequences of choosing a higheer elasticity parameter of $\epsilon = 1$, a value used in many macroeconomic analyses. We find in this

scenario that the required increase in TFP is lower than in the benchmark case (23.5% vs a 24.7%). However, the implied increase in hours worked by 2005 is higher than in the data: 18.0%, worsening the model fit non-trivially worse.

These findings lead us to the following questions: what would be the value for the parameter that best matches the patterns of hours worked over time? How far our choice is from this value? To answer these questions, we select ϵ in order to best match the profile of hours worked over time displayed in figure 4, alongside the rest of parameters and TFP levels outlined in Section 4 in the main text. This procedure yields a value of ϵ of about 0.69, close to our benchmark value of 0.75. We find in this case that implied TFP growth over the period is quite close to the benchmark case—25.2% versus 24.7%—and an increase in hours worked by 2005 near the benchmark case: 14.5%. Indeed, the predicted path for hours worked over the 1980-2005 period is quite close to the benchmark case. We also find that for the special case of tax reform only, the prediction is an increase in output of about 22.7% by 2005, versus an increase in the benchmark case of 23.0%.

Overall, we conclude from these findings that a choice of the elasticity parameter has clearly implications for the interpretation of the driving forces of the Irish miracle. This follows as under a labor supply elasticity that is non-trivially lower than macroeconomic estimates, the required increase in residual TFP to match the observed output increase is bigger and the model becomes quantitatively inconsistent with the increase in hours by 2005. We also conclude that our benchmark choice of 0.75 is close to the value that best matches the profile of hours worked over time. Thus, the quantitative predictions are quite similar between both cases.

Changes in Labor Quality As we noted in Section 2, the educational attainment of the labor force went up during the period 1980-2005. We now evaluate the potential importance of these changes alongside the baseline driving forces in this period.

As we noted earlier, Ireland average years of schooling went from around 9.9 in 1980 to about 11.9 years in 2005.[2] Using this data, we construct an index of labor quality using

[2] According to Barro and Lee (2010), years of education were 9.9 in 1980, 10.6 in 1985, 11.1 in 1990, 11.5 in 1995, 11.7 in 2000 and 11.9 in 2005.

years of schooling and Mincerian returns. We assume that as in Hall and Jones (1999), Caselli (2005) and others, individual efficiency units are given by $\exp[\Psi(s)]$, where Ψ is a function of years of schooling (s) and is determined by rates of return that vary with average years of schooling, as in Psacharopoulos (2004). Specifically, we set $\Psi(s) = 0.134s$ for $s \in [0, 4]$,

$$\Psi(s) = 0.134 \times 4 + 0.101(s - 4)$$

for $s \in (4, 8]$, and

$$\Psi(s) = 0.134 \times 4 + 0.101 \times 4 + 0.068 \times (s - 8)$$

for $s > 8$. We linearly interpolate between years of data to construct yearly indices. Overall, these calculations imply that the quality of the Irish labor force increased by about 14 percent in the period 1980-2005.

We now repeat our baseline experiment but with accompanying changes in labor quality. We find that the required changes in residual TFP from 1980 to 2005 are lower than in the original baseline experiments—about 18.6 percent versus 24.7 percent. In this case, it is worth noticing the significant complementarity between changes in labor quality and other driving forces, particularly tax reform. We note that if we repeat the experiment of a tax reform in isolation, but with the underlying changes in labor quality in the background, the effects are non-trivially larger than before. In the baseline (no change in labor quality) experiment, tax reform alone leads to changes in output of about 23.0 percent by 2005. With concomitant (but exogenous) changes in labor quality, the business tax reform implies much larger changes in output, of about 44.5 percent by 2005. Thus, changes in labor quality complement the effects of business tax reform.

Overall, it is worth noting these findings are arguably an upper bound for the potential effects driven by changes in labor quality. Neighboring countries in Europe in a similar environment, experienced much *larger* changes in an equivalent notion of labor quality and no corresponding output miracle. In France, labor quality went up by 40.6 percent. In Spain, the changes were even larger; 55.6 percent. From this perspective, one conclusion is that the potential effects of changes in labor quality in the Irish miracle were moderate. Nonetheless, given the complementarity of labor and capital in production and the amplifying effects in an open economy, the predicted effects of changes in business taxation

are substantially larger when labor quality varies.

A4.2 The Importance of Intangible Capital

So far we have conducted our analysis assuming that the share of intangible capital services in production is non-trivial, leading in turn to an overall share of movable and reproducible factors of about 53%. Our benchmark large share of capital, tangible and intangible, effectively biases our results in favor of large predicted effects of changes in business taxation, and reduces the importance of residual changes in TFP to account for the observed changes in output. We note, as others do, that it is not easy to pin down the importance of intangibles in production. Hence, understanding the quantitative implications of an alternative parameterization provides an important perspective on our findings.

In this section, we simply ask: what if the intangible share in output is (much) lower than what we assumed in our benchmark case? We assume exogenously that the share of intangibles about half of the benchmark value, $\theta_z = 0.10$ (instead of $\theta_z = 0.198$), and calibrate the rest of parameter values following the procedure described in Section 4.

We find that under $\theta_z = 0.10$, the required increase in residual TFP is 33.5% from 1980 to 2005, instead of 24.7% as in the benchmark case. The effects of changes in business taxes on output when all other forces are shut down is of about 15.8% for the period, instead of 23.0% in the benchmark case.

Interestingly, repeating the exercises in Section 6.1, we find that the effects on output from 1980 to 2005 of all driving forces if the economy is closed to capital movements is larger than in the benchmark ($\theta_z = 0.198$) case; about 60.8% vs 52.1% in the benchmark case. What accounts for this result? First, the residual increase in TFP is larger under $\theta_z = 0.10$. Moreover, as it is well known, the share of reproducible factors is a key determinant of the speed of convergence to steady states. In a closed economy, all the same, output naturally responds faster to exogenous changes when such share is small under $\theta_z = 0.10$ than under the benchmark case.

Two conclusions emerge from these exercises. First, the share of intangibles in produc-

tion is important for the quantitative interpretation of the driving forces that account for the changes in output. Not surprisingly, tax reform becomes quantitatively even less important when the share of intangible capital is reduced by about half of its benchmark value. Second, if intangibles are less important in production, then openness to capital movements becomes quantitatively less important in understanding the Irish miracle.

A5 Welfare Effects

What are the welfare effects of the Irish miracle from the perspective of our model? Answering this question provides further perspective on the quantitative role of the driving forces that we consider, as well as on the features of our environment.

Our notion of welfare changes is standard: we compute the consumption compensation that equates the discounted utility between the transition path to any new steady state and the status quo in 1980. We present results for several cases in Table A3. Not surprisingly, we find a rather substantial increase in the welfare of the representative household in our baseline experiment (column 1). We find that when all driving forces are operational, the Irish miracle in our model leads to a gain equivalent to a permanent 40.0 percent increase in consumption, starting in 1980. Despite its unusual size, it is worth noting that the required increase in consumption is much smaller than the increase in GDP by 2005.

We also find that openness matters for the welfare gains. We compute welfare effects resulting from the same driving forces as in the benchmark case but when the economy is closed to capital inflows from abroad. In this context, the *levels* of government consumption and transfers are the same as in the benchmark—i.e. they are higher as a fraction of GDP. We find that, in this case, the welfare gains are non-trivially reduced by closing the economy. Gains in this case are 21.3 percent—only a bit more than half of the gains in the benchmark case. Thus, openness clearly matters for welfare gains.

How large are the welfare gains attributable to the gradual reduction of business taxes? To answer this question, we compute the transitional dynamics driven by the changes in taxes assuming that government consumption and transfers are fixed at their initial levels. Of course, we require that the tax changes are consistent with the intertemporal budget constraint as we explained previously. We find that the resulting welfare gains are sizeable, and amount to about 4.2 percent of consumption. These gains are large by the standards of the dynamic public finance literature. This is because (i) the economy is open, (ii) reform is delayed and anticipated, (iii) the tax reform involves harmonization across sectors and (iv) the overall capital share is high.

Table A3 below presents the welfare effects (consumption compensation) associated with several cases. The first three columns are discussed in the text. The last two columns pertain to the effects of tax reform under the robustness scenarios considered in sections A4.1 and A4.2. Column 4 presents the effects of tax reform under the low elasticity of labor supply scenario ($\epsilon = 0.25$), while column 5 presents the corresponding case under the low share of intangibles ($\theta_z = 0.1$).

Table A3: Welfare gains (%)

Baseline Experiment	Baseline Experiment (Closed)	Tax Reform Only	Tax Reform Only ($\epsilon = 0.25$)	Tax Reform Only ($\theta_z = 0.1$)
40.0	21.3	4.2	3.7	2.4

Note: This table presents the welfare effects (consumption compensation) associated to selected cases. The first case corresponds to the baseline experiment with all driving forces at play. The second case corresponds to the same driving forces in the context of a closed economy. The last three cases correspond to the welfare effects of tax reform under benchmark parameter values. The first case of tax reform corresponds to benchmark parameter values. The last two are for a lower value of the labor supply elasticity ($\epsilon = 0.25$) and for a lower value of the intangible share ($\theta_z = 0.1$). In each case but the the benchmark economy, the levels (as opposed to shares of GDP) of government purchases and transfers are as in the benchmark. See the text for details.

References

Barro, R. J. and J. W. Lee (2010). A new data set of educational attainment in the world, 1950-2010. NBER Working Paper # 15902.

Broyden, C. G. (1965). A class of methods for solving nonlinear simultaneous equations. *Mathematics of Computation 19*, 577–593.

Caselli, F. (2005). Accounting for cross-country income differences. In P. Aghion and S. Durlauf (Eds.), *Handbook of Economic Growth*, Volume 1, Chapter 9, pp. 679–741. Elsevier.

Fair, R. C. and J. B. Taylor (1983, July). Solution and Maximum Likelihood Estimation of Dynamic Nonlinear Rational Expectations Models. *Econometrica 51*(4), 1169–1185.

Hall, R. and C. Jones (1999). Why do some countries produce so much more output per worker than others? *Quarterly Journal of Economics 114*(1), 83–116.

Psacharopoulos, G. (2004). Returns to investment to education: A global update. *World Development 22*, 1325–1343.

Schmitt-Grohé, S. and M. Uribe (2003). Closing small open economy models. *Journal of International Economics 61*(1), 163 – 185.

Figure A1. Ireland's GDP per adult relative to the United States.

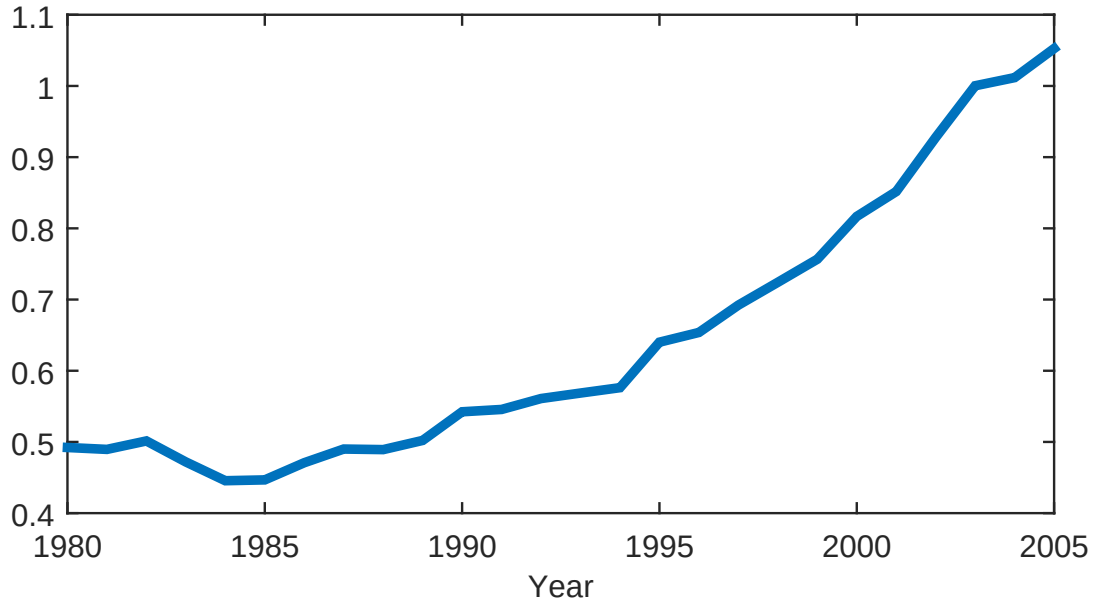


Figure A2. Ireland's ratio of GNP to GDP.

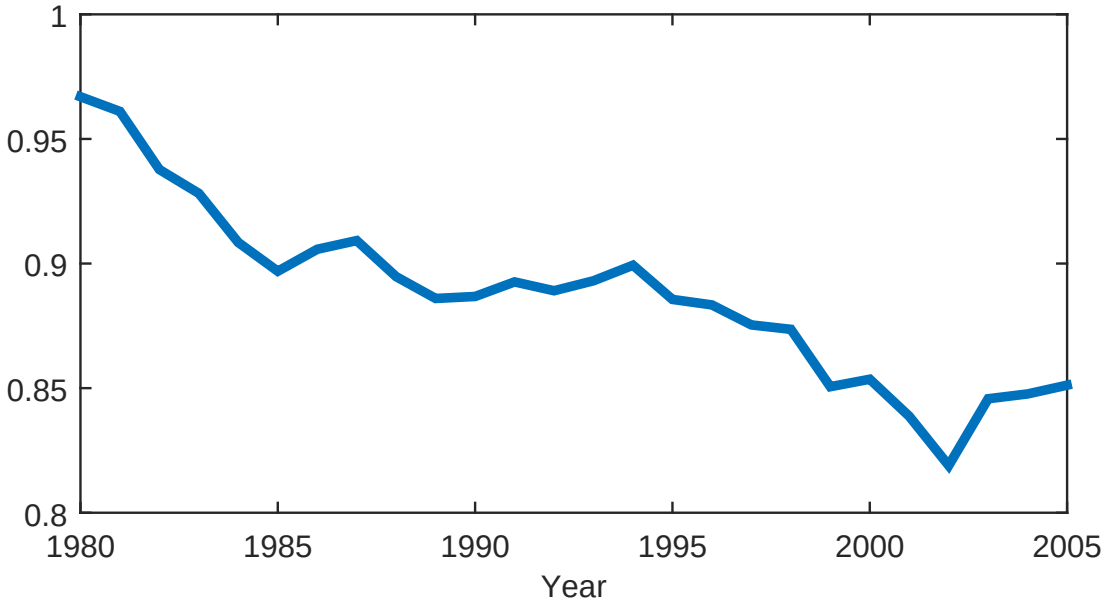


Figure A3. Output: model vs data

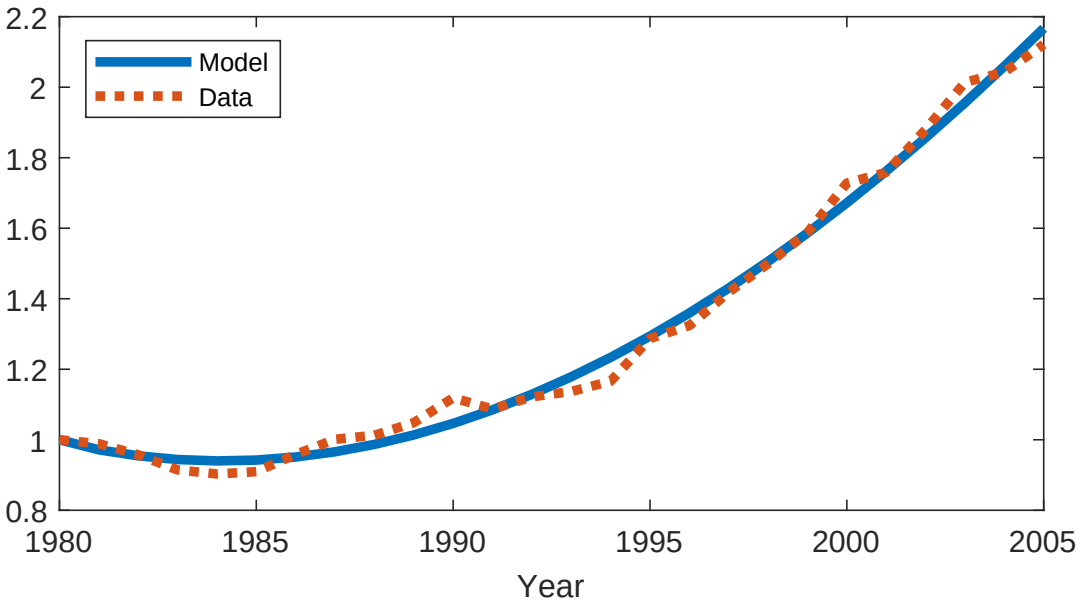


Figure A4. Consumption to Output Ratio

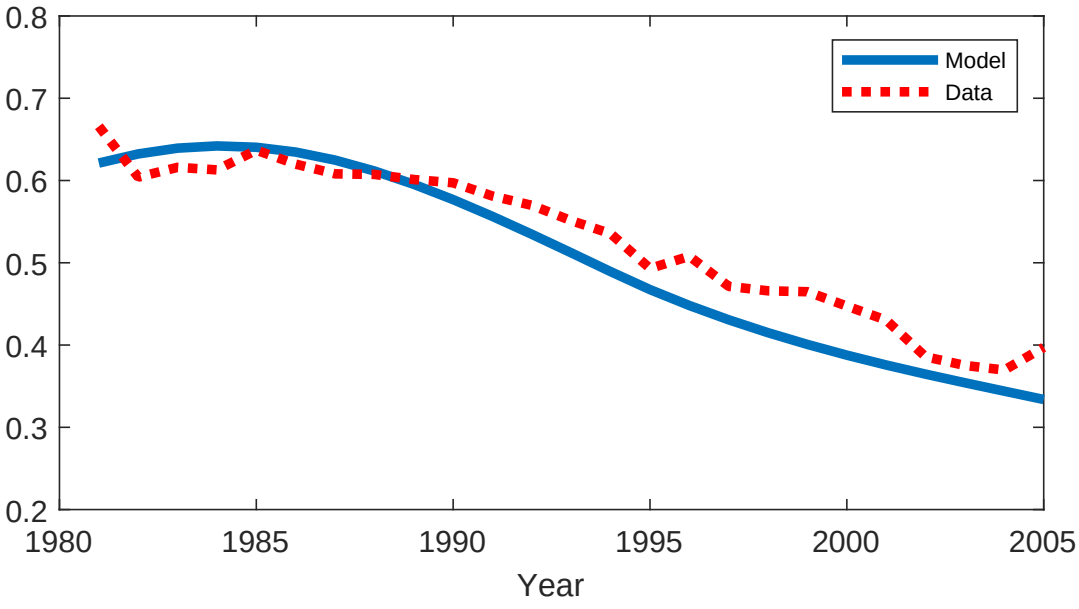


Figure A5. Output per adult: perfect foresight versus static expectations