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Nominal Rigidities and Economic Fluctuations: The Case of Puerto Rico

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RESUMEN

This paper studies the importance and impact of price and wage rigidities on economic fluctuations in Puerto Rico. To this end, a DSGE model with nominal rigidities and monopolistic competition is estimated with macroeconomic data for Puerto Rico. Among the main results, it is estimated that over 79 percent of firms do not readjust their prices at any given period in Puerto Rico, a share that has, on average, been 14 percentage points higher than in the United States. Moreover, prices became more rigid after 2000 during the deflationary period of the recession. This constitutes evidence that firms rarely pass savings from cost reductions to consumers in Puerto Rico by reducing prices, and reduce prices less often, on average, than firms in the United States during periods of economic contraction (when prices would be expected to fall by more due to reduced demand). This has the effect of worsening the magnitude of economic recessions in Puerto Rico, as income falls for firms and individuals while costs remain constant.

RESUMEN BIOGRAFICO

Emanuelle Alemar Sanchez nació el 16 de enero de 1997 en Rio Piedras, Puerto Rico. Obtuvo su diploma de Escuela Superior de la Academia Regional Adventista del Este en Rio Grande. Realizó su Bachillerato en Artes con Concentración en Economía, con doble énfasis en Métodos Cuantitativos y Crecimiento Económico en la Universidad de Puerto Rico, Recinto de Rio Piedras, donde se graduó Magna Cum Laude en el 2019. Durante el bachillerato, fue seleccionado y participo en programas de verano en Carnegie Mellon University, y en el programa de verano de la American Economic Association en Michigan State University, donde tomo cursos avanzados en economía, estadísticas y econometría, además de haber colaborado en dos investigaciones.

Alemar se ha destacado desde temprana edad por su labor como analista económico y de datos en firmas e instituciones financieras como Inteligencia Económica, Inc., Estudios Técnicos, Inc y Banco Popular. En el programa graduado de Economía, se desempeño como asistente de catedra para los cursos de Estadísticas y Econometría I y II a nivel graduado, así como asistente de investigación, fungiendo como coautor de 3 investigaciones sobre aceptadas para publicación en revistas arbitradas en Puerto Rico y América Latina. Estas investigaciones tratan sobre el impacto de cambios en oferta y demanda agregada sobre el mercado laboral, Actualmente, labora como Analista de Política Pública e Investigación para la Junta de Supervisión Fiscal.

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A la honra y memoria del profesor Jaime Benson Arias, quien se convirtió en mi primer mentor en esta profesión, y quien siempre me esperaba con la puerta de su oficina abierta cada vez que acordábamos para reunirnos y dialogar sobre macroeconomía y otros asuntos relacionados a mis planes académicos y profesionales. Su amor por el estudio de la economía de Puerto Rico vive en mi y en sus estudiantes.

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1 Introduction

An important topic that has often been discussed in the literature on the Puerto Rican economy concerns the effects of external shocks on inflation and economic activity in the Island. Nonetheless, none concerns the role of internal propagation mechanisms present in the Puerto Rican economy that can enhance these external shocks to alter the trajectory of inflation and economic activity in the short run, nor the impact of firm market power and bargaining power in the labor market on inflation and macroeconomic fluctuations in the Island.

In this paper, I study the role and importance of nominal rigidities (stemming from firm market power and wage bargaining power in the labor market) as a potential propagation mechanism of external shocks on the Puerto Rican economy, and thus, as an exacerbator of economic fluctuations in Puerto Rico. To this end, a version of the Real Business Cycle model proposed by Hansen (1985) that incorporates the extension of staggered pricing as in Calvo (1983) and staggered wage setting as in Erceg et. al. (2000) is estimated with macroeconomic data from Puerto Rico using Bayesian techniques. Estimates of the degrees of price and wage rigidities in the economy are obtained and the effects of shocks that put pressure on prices and wages to change are simulated under these estimated degrees. This in turn allows us to estimate how rigid are prices in Puerto Rico compared to prices in the United States by comparing our estimates to those from previous studies for the U.S.

I find that prices take longer to change or adjust in Puerto Rico than in the US following events that cause prices to change, mainly after events that cause them to fall. This is caused by a smaller proportion of firms in the aggregate lowering prices for consumers in response to reductions in costs of production in Puerto Rico relative to the US, which is in turn a consequence of several unique elements of the Puerto Rican economy that constitute barriers to entry for new companies and thus concentrate market power in a small number of firms in each market. The few firms that continue to operate in each market have more incentive to not change (mainly to not reduce) their prices when they would be expected to do so, such as periods of economic contraction via reduced aggregate demand.

The initial hypothesis of this paper asserts that nominal rigidities explain a larger portion of the changes in economic activity in Puerto Rico, mainly the contractions in economic activity, than in the United States. Thus, nominal rigidities constitute a significant propagation mechanism of external shocks in the Puerto Rican economy, exacerbating the magnitude and persistence of fluctuations in real economic activity in response to policy shocks that negatively affect aggregate demand, such as reductions in transfer payments to families or increases in interest rates. After such events, prices do not fall as they would be expected to in response to the contraction in demand, mainly prices of intermediate goods and goods sold in markets at higher levels of the supply chain, in which there tends to be less competition. Thus, the revenue of firms that sell final goods collapses while their costs remain constant, making the economic contraction more severe.

The outline of this paper is as follows. In the next section, I review the literature on the role of nominal rigidities as a propagation mechanism for the effects of demand-management policy, as well as on the relevant foundations and institutional aspects of the economy of Puerto Rico that are taken into account in the theoretical model. In section 3, we present the theoretical model along with the equilibrium conditions. Section 4 presents the Bayesian technique employed to obtain estimates of some of the model parameters. Results are discussed in Section 5, while section 6 presents concluding remarks and possible policy implications that emerge from the analysis.

2 Literature Review

2.1 Evolution of the Puerto Rican Economy after the Post-War period and Key Institutional Aspects

Since mid 20th century, the Puerto Rican economy has undergone several fundamental transformations that have played a significant role in its long-run behavior. Following the end of WWII, the economy underwent a significant expansion as a consequence of the development efforts that were put forth by the local and federal governments (aided by the global economic stability that was characteristic of the post-war period). From 1947 to 1973, the Island's economy grew at average rates of over 4 percent (Rodríguez and Toledo, 2007). Nonetheless, as a consequence of the erosion of the comparative advantages of the development program known as Operation Bootstrap and external factors such as the 1973 oil shocks, the economy began to face stagnation problems. Growth has since remained sluggish relative to the pace of growth experienced during the post-war expansion period

(Catalá, 1998; Rodríguez, 2004, 2017).

From the adoption of the industrial program known as Operation Bootstrap as the main development strategy during the Post-War up until the period of Section 936 of the Internal Revenue Code of the United States, the predominant economic policy in the Island has been mainly an industrial, supply-side type of policy (Rodríguez, 2017). As Dietz (1989) points out, the main objective of this policy strategy has been the attraction of foreign investment, particularly in high technology sectors, as a means to foment job creation and growth. Such a policy strategy has been practiced through the use of fiscal incentives in the form of tax exemptions and subsidies for qualifying foreign firms (Dietz, 1989).

Prompted by the incentives[1] provided by Operation Bootstrap, the island underwent a significant industrialization process that consisted of two main phases, a phase in which firms attracted were mostly labor-intensive and another in which firms attracted were much more capital intensive. During the first phase (1947-1956), the majority of the firms that were attracted consisted primarily of textile manufacturers. Rodríguez (2004) exerts that the comparative advantages of this industrialization stage quickly eroded after tariffs on textiles imported from the Far East were lowered and after the implementation of the US federal minimum wage on the island, as these firms already generated low levels of profits and these factors represented a substantial increase in costs. In response to the erosion of the comparative advantages of this stage, incentives were redirected towards more capital-intensive industries, such as the petrochemical and pharmaceutical industries. Villamil (1975) and Dietz (1989) point out that the incentives provided to these firms were not only fiscal, but environmental as well due to the highly-polluting and energy-intensive nature of their production activities.

Ruiz and Zalacaín (1996) exert that the lack of complemental instrumentality has exacerbated such a dependence on tax incentives as the main tool of economic policy in the Island. According to Dietz (1989), incentives granted by the local government in order to attract foreign investment had to be sufficiently generous up to the point where establishing operations on the Island was "irresistible" for American and foreign firms.

Although, as highlighted by Benson (1993), the development strategy prompted by

[1]These incentives were exemptions on municipal, property and patent taxes to qualifying companies, as well as subsidies in the form of the sale of buildings built by the government at a fraction of their market price.

Operation Bootstrap was successful in its main objectives as evidenced by a substantial growth in output, personal income and consumption during the period ranging from the beginning of the initial phase up until the end of the second phase (1947-1973), the economy began to show signs of weakness and sluggish growth after the 1973 oil price shocks. Catalá (1998) exerts that the relative stagnation experienced during the 1970's can be attributed to the erosion of the comparative advantages of the second phase of the industrialization process, namely low salaries and low oil prices. Moreover, according to Rodríguez (2017), the development strategy based on the attraction of foreign capital resulted in an increase in the vulnerability of the economy to external shocks. The ability to alter the trajectory of the economy internally was greatly reduced as the development strategy based on the attraction of foreign investment lead to an increase in the dependence of the local economy to policy decisions taken outside of the Island (Villamil, 1979).

In response to the stagnation of the mid 1970's, Section 936 of the Internal Revenue Code was enacted in 1976. This section exempted subsidiaries of American firms whom established operations in the Island from federal corporate income taxes. The main purpose of Section 936 was, once again, to attract foreign investment. The bulk of the firms that settled operations in the Island to take advantage of this incentive were concentrated in the high-technology manufacturing sectors, particularly in the pharmaceutical and chemical products industries[2] (Dietz, 1989). According to Toledo (2006), the most important industry in the manufacturing sector by the year 2000 was production of medicines. The importance of this industry was not limited to the Island, as it extended heavily to the US mainland. In 1997, pharmaceutical output in Puerto Rico as a share of industry output in the US was at 24 percent. Given that this industry is composed mainly of North American corporations and that it is a capital-intensive industry, it is directly affected by technological innovations in the United States (Toledo, 2006).

As highlighted by Quiñones (1993), the incentives provided by Section 936 contributed to the growth of a dynamic high technology sector, as more than 60 percent of the 936 firms are in the pharmaceutical, clothing, machinery and scientific and professional instrumentation industries (Catalá, 1993). Thus, the creation of this incentive represented the perpetuation of the growth model based on the attraction of foreign investment after the

[2]For instance, the relative contribution of manufacturing to GNP grew from 25.4 percent in 1970 to 48.1 percent by 1980.

1970's (Rodríguez, 2017). Dietz (1989) exerts that establishing operations in the Island became highly profitable for pharmaceuticals as such firms could test their products without major restrictions and to operate in a less regulated environment, while close to 50 percent of their profits were generated in the Island. Rodríguez (2004) stresses that these firms generated a substantial number of jobs and investment, while their activity was a source of revenues for the local government through taxes on the repatriation of profits, income and dividends.

Nonetheless, in August 20, 1996, Section 936 was overturned by then President Bill Clinton over the observation that the Island had become a tax haven for American manufacturing firms, while a 10-year transition period for the phase-out of the incentives was conceded. As the government seeked for alternative ways to stimulate industrial development in response to the imminent phase-out of Section 936 incentives, Catalá (1993) asserts that the flaw in this reasoning is the assumption that there was instrumental complementarity for American firms in the Island under Section 936, as the only significant attraction seemed to have been the tax incentives.

The complete phase-out of the incentives provided by Section 936, along with other factors such as the global recession fueled by the 2007-2009 financial crisis along with high oil prices, and the downgrade of local government bonds as consequence of the growth of public indebtness relative to output growth, have led the economy into a prolonged period of recession since 2006 from which it has not been able to recover. From 2006 to 2018, the economy, as measured by the year-over-year growth rate of real GNP, has contracted every year with the exception of fiscal year 2012, in which a positive but small growth rate of 0.5 percent was registered[3].

On the other hand, the lack of adequate and independent policy tools from the local government as a consequence of the high level of economic integration with the United States, particularly in the aspect of demand management policy, has exacerbated the economic problems of the Island. This is discussed by Rodríguez (2004) as one of the main factors that has led the government to further recur to policies on the supply side, mainly those based on the attraction of foreign investment through tax incentives (Rodríguez, 2004, 2017).

[3]Statistical Appendix of the Economic Report to the Governor 2016-2018, table 2.

Particularly, the Constitution of the Commonwealth of Puerto Rico imposes two important constraints on the execution of fiscal policy on the Island. Namely, it establishes that the central government's budget must be balanced by the end of every fiscal year[4], and that debt payments must be prioritized over any other item on the budget[5] (Constitution of the Commonwealth, 1952). These legal constraints imply that fiscal policy has to be pro-cyclical, which greatly limits the ability of the Government to conduct independent demand management policy, as well as the effectiveness of such policy (Rodríguez, 2004, 2017 Rodríguez y Toledo, 2007). Pro-cyclicality of fiscal policy in this context implies that spending goes up and taxes go down in economic expansions, while spending goes down and taxes go up in recessions (Alesina and Tabellini, 2005).

Although the government has been able to enact anti-cyclical policy through the emission of extra-constitutional debt, factors such as the excessive growth of both constitutional and the latter type of debt and the generalized distrust from the private sector and markets have limited the effectiveness of this alternative (Rodríguez, 2004). According to Curet (2003), the organizational and administrative nature of the local government since the 1970's has contributed to the overall economic instability that has predominated in the last four decades, as the administrations that have taken power since have broken the continuity of policies for economic development.

Another factor contributing to the limited ability of fiscal policy consists in the adoption of the model of industrialization by invitation. Benson (1993) highlights that while foreign firms were receiving generous tax incentives, the local government had to raise enough revenue to provide these firms with an adequate, low-cost infrastructure (Meléndez, 1984). This further implies that many of the fiscal policy efforts by the government have been focused towards artificially enhancing the effectiveness of supply side policies by providing infrastructure and other incentives in addition to the tax incentives that these firms were already receiving.

In the monetary aspect, demand-management policies have been very limited as well. According to Tobin (1976) in his "Informe al Gobernador del Comité para el Estudio de las Finanzas en Puerto Rico" (known as the Tobin report), the adoption of the US dollar as the official currency along with the integration of the monetary and financial system of

[4]Article VI: General Dispositions, Section 7.
[5]Article IV: General Dispositions, Section 8.

the Island to that of the United States have made it impossible for Puerto Rico to enact independent monetary policy. This author asserts that, without a national currency of its own, the government cannot coordinate monetary and fiscal policy to monetize its debts and must borrow at a competitive cost in the primary bond market. Additionally, there exists free mobility of funds, capital and labor between both, the US and Puerto Rican economies. These factors have led the Island to be considered as a region of the United States, at least in the monetary policy aspect (Gutierrez, 1983; Benson, 1993; Rodríguez and Toledo, 2007).

Particularly, Tobin (1976) points out that regionality in terms of monetary policy implies that funds flow freely between the two economies seeking higher returns while the benchmark interest rate is determined in the national economy (the United States in this case with the federal funds rate, the target interest rate of the Federal Reserve, as the benchmark rate). This factor, as Rodríguez and Toledo (2007) point out, along with the adoption of the US dollar as the official currency, imply that the Island cannot coordinate fiscal and monetary policy to monetize its debt and its money supply is a proportion of the money supply of the United States. Thus, actions taken by the Federal Reserve in the pursuance of its dual mandate have been found to have significant real and nominal effects on economic activity in the Island. In this particular, Rodríguez and Toledo (2007) show that any action taken by the Federal Reserve through any of its three main policy instruments transmits to prices in the short run and to the real economy in the long run. In this case, the main transmission mechanism of monetary policy to the real economy is the interest rate targeted by the Federal Reserve.

Given the local government's limited ability to enact demand-management policies in both, the monetary and fiscal context, the federal government has played a huge role in sustaining the levels of consumption demand adopted during the "Golden Period" (1947-1973). In this regard, Benson (1993) postulates that factors such as the full extension of the food stamp program in 1974 and the creation of the 936 fund local financial market[6] in 1976 were crucial in compensating for the contractions in output and income observed in the

[6]Transnational corporations that settled operations in the Island under Section 936 received incentives to deposit funds in local commercial banks. These incentives were tax exemptions on corporate local financial investments. In 1977, one year after the enactment of Section 936, the share of corporate deposits relative to total deposits increased to 51 percent (from 42 percent in 1976).

1970's that marked the end of the "Golden Period" expansion. The substantial increase[7] in federal transfer payments to families and individuals had the direct effect of increasing their real income, implying an increase in purchasing power among those with a high propensity to consume (Choudhurry, 1975; Benson, 1993). Additionally, such factors implied an increase in the supply of credit in the economy, which according to this author, explained much of the development of the consumer credit establishment that contributed to the sustainment of consumption demand. Such a dependence of the demand side of the economy, specifically of consumption demand, on federal transfers has not ceased, but it has only intensified over time[8]. Rodríguez (2004) highlights that federal transfers have cushioned the standard of living of Puertoricans in the midst of instability reflected by declines in GNP, high levels of unemployment relative to those of the mainland and a reduction of domestic fixed capital investment after the 1990's.

From the previous discussion, the following points stand out:

1. Economic policy in the Island has been mainly an industrial, supply-side type of policy, which has focused on the attraction of foreign investment in high technology sectors since the late 1970's. This has rendered the economy more vulnerable to expected and unexpected changes in the state of technology.

2. Fiscal policy has been conducted in a pro-cyclical manner. By Constitutional mandate, the government's budget has to be balanced at the end of each fiscal year. Additionally, the worsening fiscal situation has limited greatly the ability to enact expansionary fiscal policy. The extent to which local fiscal policy can be effective has been limited due to the general distrust of the public and debt markets on the local policy process. Moreover, the resources for fiscal policy have rather been directed towards aiding the main supply side policy of foreign capital attraction through the grant of additional incentives to foreign firms.

3. The money supply in Puerto Rico has been determined exogenously by the Federal Reserve through the use of policy rules that do not take into account economic ac-

[7]For instance, Benson (1993) highlights that from 1975 to 1978, the amount of funds assigned to food stamps in the Island grew at an average rate of 30.4 percent.

[8]Real transfers to individuals as a share of real personal income grew from 20.2 percent in 2000 to 27 percent in 2016.

tivity or inflation in the Island[9]. Due to the adoption of the US dollar as the official currency and the integration of the Island's banking system to that of the United States, Puerto Rico can be considered as a region of the United States in terms of monetary policy. The reference interbank loan rate for commercial banks in the Island is the federal funds rate, targeted by the Federal Reserve through its three traditional policy instruments.

4. Even during periods of economic expansion, substantital levels of unemployment have prevailed. The lowest average unemployment rate from the 1950's up until 2002 was 10% (Rodríguez and Toledo, 2007).

5. A significant portion of the internal money supply has been determined by foreign investment through the accumulation of the 936 funds deposited in commercial banks, as well as by transfers from the federal government.

6. Transfers from both, the federal and local governments, have constituted a significant share of the income of families and have helped preserve consumption patterns from high income growth periods.

2.2 Nominal Rigidities and Demand-Management Policies: Theory and Overview of the Literature

2.2.1 Wage Rigidities

The idea that wages are not perfectly flexible and can take time to adjust was first suggested by John Maynard Keynes in his seminal work, the General Theory of Employment, Interest and Money (Keynes, 1936, p.27) in an attempt to explain the high levels of unemployment observed during the Great Depression. For instance, if nominal wages failed to adjust downwards in the event of a contraction in aggregate demand, involuntary unemployment would surge because the real wage would increase (assuming prices are flexible and adjust after the contraction in demand). At this higher real wage, the supply of labor willing to work for the same nominal wage would exceed the demand for labor by firms at that same nominal wage (because the real wage is higher after the fall in prices due to the contraction in demand).

[9]At least explicitly.

Nonetheless, in what regards to policy to mitigate unemployment, Keynes did not acknowledge inflexibilities in wage adjustment as a central idea in his explanation of involuntary unemployment, stating that the "essential character of the argument is precisely the same whether or not money-wages are liable to change" (p. 27). Even if wages were perfectly flexible and could adjust downward (or were forced downwards by a wage cutting policy), Keynes stated that such reductions could only restore full employment under circumstances that were unlikely to be met after a contraction in demand, such as perfect flexibility of the interest rate[10] (not possible under a liquidity trap) (Snowdon and Vane, 2005). Thus, with regards to the ideal policy to combat unemployment following a contraction in demand, he argues against a 'flexible wage' policy in favor of a 'flexible money' policy in the form of fiscal or monetary stimulus. Under rigid nominal wages, such a policy would result in an increase in aggregate demand which would translate into higher prices. As a consequence, the real wage would fall and labor demand would increase, restoring full employment if the increase in aggregate demand resulting from the policy compensates entirely for the initial contraction.

Although Keynes implicitly acknowledged the existence of wage rigidity, the idea is further developed, and its importance is further highlighted, by Modigliani (1944) as part of the "hydraulic" interpretation of Keynes' work (Hicks, 1937; Klein, 1947; Samuelson, 1948; Hansen, 1953). This author analyzes the extent to which the results of the Keynesian theory can be due to a refined theoretical approach of liquidity preference or to the assumption of wage rigidity and argues that wage rigidity is sufficient by itself to explain the entirety of involuntary unemployment with the exception of the limiting case highlighted above of a liquidity trap. Wells (1979) argues against this interpretation of Keynes' work provided by Modigliani, mainly against the idea that involuntary unemployment can only be explained by rigid wages, as he argues that real wages do not fall in response to an across-the-board reduction in nominal wages. If nominal wages are cut in an attempt to reduce the real wage and increase employment, aggregate demand will decrease as the wage bill is not only a source of cost for firms, but it is a major source of income for families. This will lead to an episode of deflation, which would in turn result in real wages being unchanged and thus employment not increasing in response to the wage cutting policy, while income and prices

[10] To the extent that the interest rate can adjust downwards after an increase in the real value of the money supply (due to a subsequent fall in prices when wages are cut), then investment demand can increase and thus full employment can be restored without the need of an expansionary demand-management policy.

being further depressed (Wells, 1979).

Fischer (1977) incorporates wage rigidities in the form of two-period, non-indexed contracts and indexed contracts into a rational expectations model and tests the neoclassical theoretical conclusion of monetary policy having no effect on output in the short run, except for when the policy is not anticipated. In the case of two-period labor contracts, he shows that monetary policy can affect real output even if the policy is fully anticipated by agents in the model, as the information of such a policy becomes available after the contract is made.

Taylor (1980) develops a rational expectations model in which wage contracts are the exclusive source of rigidity. In turn, this rigidity constitutes an endogenous propagation mechanism for aggregate demand shocks in the model. The assumption that all wage contracts are staggered (not all wage decisions are made at the same time) implies that firms and unions must look forward and backward in time when setting the wage to be paid during the contract period. In this context, the effect of demand shocks (induced or not by policy) on unemployment are exacerbated significantly as some contracts will still be in place in the future. Until nominal wages can be readjusted when the contract ends, the amount of labor demanded will decrease. In general, the model with contracts lasting as long as 3 or 4 quarters can generate a persistence of unemployment over time similar to that observed in the United States with no other sources of persistence.

The results of Fischer (1977) and Taylor (1980) highlight the important role that wage rigidities in the form of contracts can play in exacerbating the effects of aggregate demand contractions, and, subsequently, in enhancing the effects of demand-management policy directed at mitigating such contractions. Fischer's results highlight the particular importance of the role that activist demand-management policy can play in stabilizing output under wage rigidities when agents negotiate contracts in nominal terms for "periods longer than the time it takes the monetary authority to react to changing economic circumstances". Nonetheless, it should be noted that these authors do not take into consideration how the real effects can vary under different types of contracts. Stiglitz (1984) argues that unless implicit contracts have limitations on the complexity of the contract that could be designed or search is costly and cannot be monitored in the contracts, these contracts can be associated with rigid wages, but not necessarily with unemployment. In particular, this author considers two types of theoretical explanations underpinning observed rigidities in wages, namely the theory of implicit contract and efficiency wage theory and concludes that the efficiency wage theory provides a better explanation for the wage rigidity that causes cyclical unemployment than theories based on implicit contracts[11].

2.2.2 Price Rigidities

Mankiw (1991) exerts that wage rigidities by themselves cannot reproduce the observed positive co-movements in output and the real wage that are characteristic of recessions. He notes that if output and the real wage were inversely related as a result of wage rigidity, then the event of a recession would be popular because although unemployment would arise, most of those that remain employed would enjoy of a higher real wage. The author refers to this dilemma as the "real wage puzzle", and he argued that such a puzzle could be solved by taking into account imperfections in the goods market that might be triggered by price rigidities such as 'menu' costs (the costs related to changing prices in the short run) (Snowdon and Vane, 2005).

Mankiw (1985), Akerloff and Yellen (1985) and Parkin (1986) show that even small menu costs can generate substantial price rigidity for firms operating in imperfectly competitive markets. In such a setting of market power by firms, their sales will not decrease dramatically if they increase prices marginally. Nonetheless, reducing prices can be very costly for the firm because, although its sales will increase if it reduces prices, it will earn less revenue per unit sold (Snowdon and Vane, 2005). In this case, if the cost of adjusting prices is greater than the additional profits the firm would earn by reducing its price following a contraction in demand, the firm will not reduce its price. Firm profits will grow at a rate that is lower for every additional reduction in prices (because marginal revenue is reduced), implying second-order reduction of profits. This implies that even small 'menu' costs can result in a substantial degree of price rigidity at the aggregate level.

It should be noted that such a mechanism is not necessarily analogous in the case of an expansion in demand that puts upward pressure on prices. In this regard, Mankiw (1985) writes: "Private incentives produce too much price adjustment following an expansion in aggregate demand and too little price adjustment following a contraction in aggregate de-

[11]For instance, Stiglitz (1984) stresses that if all states of nature are observable at the time of signing the employment contract, then such an implicit contract would specify the amount of labor and wage paid in each state, and thus the implicit contract would not result in unemployment over time.

mand. From the viewpoint of a social planner, the nominal price level may be "stuck" too high, but it is never "stuck" too low. In this sense, prices are downwardly rigid but not upwardly rigid." (Mankiw, 1985). Carlton (1986) suggests that price rigidity is monotonic in concentration, implying monopolies change prices less often than duopolies, duopolies change prices less often than an oligopoly of three competitors, and so on.

Rotemberg (1987) refers to the observation that small menu costs can generate substantial degrees of price rigidity as the PAYM insight, named after the works of Parkin (1986), Akerloff and Yellen (1985), and Mankiw (1985). The main point of this insight is that the societal costs of price rigidities are much larger than the private costs for firms, as small menu costs in aggregate demand can generate very large and inefficient fluctuations in aggregate output in response to exogenous changes in demand. According to Mankiw, such large fluctuations are due to firms exercising their market power by restricting output. In a general equilibrium context, if an intermediate goods producing firm fails to reduce its price after a contraction in demand, the costs of other firms that buy intermediate goods from the latter would remain the same, thereby reducing the incentives of the final goods firms to reduce prices. In this case, less output will be demanded due to the failure of prices to adjust, and the effects of the initial contraction in demand will be exacerbated.

In the Calvo (1983) pricing model, a random fraction of monopolistically competitive firms in the economy are unable to reset their prices every period. Even though firms operating in monopolistic competition are price-setters, they might be unable to adjust their prices in any given period due to factors such as menu costs or long-term contracts. This implies that, in response to an anticipated or unanticipated change in demand induced by policy, firms cannot change their prices instantaneously. Thus, costs of production (prices of intermediate goods) remain constant for some firms and this causes the change in policy to have a real effect on output in the short run until price-setting firms in the intermediate goods market re-adjust prices.

2.2.3 Existence and Extent of Nominal Rigidities in the Puerto Rican Economy

In light of the economic instability in terms of declining real output and high levels of unemployment relative to those of the United States, one can point out to nominal rigidities as a potential source of the volatility of real output and unemployment in Puerto Rico in recent decades. In particular, although there is no empirical evidence to date regarding the extent and importance of such rigidities in accounting for this volatility, the anecdotal and legal evidence suggests to an extent the existence of nominal rigidities in the economy. Particularly, according to Rodríguez (2004), generalized factor price increases were exaggerated in food markets due to quasi-monopolistic conditions in the 1970's. In response to the increase in industry concentration in food markets, the Planning Board of Puerto Rico formally called for an expansion of the Antitrust section of the Justice Department and for the design of policy that would encourage competition. Nonetheless, policy talks were not resumed.

In regards to the lack of competition and industry concentration, Ruiz (2005) asserts that the limitation of free enterprise that is generated by the operations of multinational chain stores has led small and medium businesses to ask for greater protection in light of the inequality they confront in terms of competitiveness. This author points out to natural barriers to entry, access to transportation, labor force concentration, traffic, among others, as factors that enhance market concentration and lack of competition in the Island. She highlights that the local market is a highly cocentrated one, with market quotas splitting between a group of 4 to 5 competitors. In particular, when a multinational chain store opens in an area with a relatively static population due to the geographical reality, it can capture a significant share of the market. As a consequence, the remaining stores of much smaller size selling similar products end up with a smaller market share, and can even be forced to close (Ruiz, 2005; Alameda, 2002). Such a high level of market power can act as a source of substantial downward price rigidities.

Moreover, legal evidence suggests that wholesale distributor firms can have more protection in contractual relationships of sale and distribution in case the principal firm ends or refuses to renew a distribution contract[12]. This can be a source for longer than usual duration of price contracts in the Puerto Rican economy, potentially leading to higher degrees of price rigidity. Another legal provision that can be considered as an exclusive source of price rigidity in Puerto Rico corresponds to Section 27 of the Merchant Marine Act of 1920, better known as the Jones Act. This provision requires that all waterborne shipping be-

[12]In particular, Law 21 of 1990 prohibits a principal from terminating its agreement with an exclusive sales representative without just cause. This law is modeled after Law 75 of 1964, also known as the Dealer's Contract Act, designed to protect Puerto Rican "dealers" from a manufacturer's arbitrary termination or impairment of their commercial relationship (R.A Fleming, 2017).

tween points in the United States be carried by vessels built in the United States are owned and operated by Americans (Fritelli, 2003). Grennes (2017) notes that 'by excluding foreign suppliers, the Jones act reduces competition for shipping services'. This author highlights that there are four companies serving Puerto Rico from Jacksonville, Florida. According to the author, these companies have been accused of collusion, with their executives being convicted of conspiring to fix freight rates on routes from Florida to Puerto Rico.

With regards to wage rigidity, Rodríguez (2004) states that the implementation of the US minimum wage floor in the Island accentuated the deterioration of the comparative advantages of the first stage of industrialization. He points out to compliance with such a wage floor as the main driver of inflation in this period. This constitutes one of the reasons why firms in the second stage were much less labor intensive. Thus, in general, one can refer to the minimum wage as being a legal source of nominal wage rigidity in the Island[13].

In the next section, I present the theoretical model by taking into account the particularities of the economy highlighted in the previous section and obtain the equilibrium conditions. I then obtain estimates of the average degrees of price and wage rigidity in the Island using Bayesian techniques and simulate the macroeconomic impact of changes in demand-management policies in the form of transfers under the estimated degrees of price and wage rigidity.

3 The Model Economy

Our model economy is a version of the economy represented by the Hansen (1985) real business cycle DSGE model with staggered pricing as in Calvo (1983) and wage setting as in Erceg et. al. (2000).

3.1 Firms

The production side in our model is divided into two sectors of firms, an intermediate goods producing sector and a final goods producing sector.

[13]Other possible sources of such a type of rigidity could be high degrees of unionization and bargaining power by workers, although this would be less prone to be the case in economies with high unemployment levels such as that of Puerto Rico.

3.1.1 Final-Goods Sector

Firms in the final-goods sector operate under perfect competition and combine a continuum of intermediate-goods, indexed by $0 < k < 1$, to produce final-goods according to the production technology

$$Y_t = \left(\int_0^1 Y_t(k)^{\frac{\psi-1}{\psi}} dk \right)^{\frac{\psi}{\psi-1}} \tag{1}$$

Where $Y_t(k)$ corresponds to the amount of intermediate good k that is combined with other goods to produce Y_t, and ψ is the elasticity of substitution between intermediate goods[14].

The problem solved by a profit-maximizing final goods firm is given by

$$\max_{Y_t(k)} P_t \left(\int_0^1 Y_t(k)^{\frac{\psi-1}{\psi}} dk \right)^{\frac{\psi}{\psi-1}} - \int_0^1 P_t(k) Y_t(k) dk \tag{2}$$

where the final goods technology has been substituted. Differentiating with respect to $Y_t(k)$, the first order condition for this problem can be obtained as

$$P_t \left(\int_0^1 Y_t(k)^{\frac{\psi-1}{\psi}} dk \right)^{\frac{1}{\psi-1}} Y_t(k)^{\frac{-1}{\psi}} - P_t(k) = 0 \tag{3}$$

solving this condition for $Y_t(k)$ yields the demand function for an intermediate good k:

$$Y_t(k) = Y_t \left(\frac{P_t}{P_t(k)} \right)^{\psi} \tag{4}$$

Substituting this expression in the production technology, we obtain

$$Y_t = Y_t \left[\int_0^1 \left(\frac{P_t}{P_t(k)} \right) \right]^{\frac{\psi}{\psi-1}} \tag{5}$$

[14]Small values of ψ imply that intermediate goods are less substitutable, implying intermediate goods firm have more market power.

rearraninging in terms of prices yields

$$P_t = \left[\int_0^1 P_t(k)^{1-\psi} dk \right]^{\frac{1}{1-\psi}} \tag{6}$$

which is the pricing rule for firms in the final goods sector.

3.1.2 Intermediate-Goods Sector

Firms in the intermediate-goods market operate under monopolistic competition. These firms produce differentiated goods and thus have power to set prices above marginal costs. A random fraction $0 < 1 - \rho < 1$ of firms gets to adjust their price to the optimal price each period. We assume that the remaining fraction ρ of firms who cannot adjust their price to the optimal price keep their prices unchanged[15]. Intermediate-goods firms produce differentiated goods, indexed by $0 < k < 1$, according to the production technology

$$Y_t(k) = z_t K_t^{\theta}(k) H_t^{1-\theta}(k) \tag{7}$$

where θ is the fraction of capital used in production and z_t is a scale variable that corresponds to total factor productivity. In particular, we assume that TFP evolves as an AR(1) process in logarithm,

$$\ln z_{t+1} = \gamma \ln z_t + \epsilon_{t+1}^z \tag{8}$$

where γ is the degree of persistence of technology in the economy and ϵ_{t+1}^z is a technology shock with mean zero and constant variance, namely $\epsilon_{t+1}^z \sim (0, \sigma_z^2)$. Firms that get to choose prices in period t will do so as to maximize the discounted present value of profits during the period over which the chosen price is in effect. This problem can be expressed as

[15]Possible alternative specifications could be updating prices by a steady state gross inflation rate or by a one-period lagged realized gross inflation rate.

$$\max_{P_t^*(k)} E_t \sum_{j=0}^{\infty} \beta^i \rho^i \left[P_t^*(k) Y_{t+i} \left(\frac{P_{t+i}}{P_t^*(k)} \right)^{\psi} - P_{t+i}(r_{t+i} K_{t+i}(k) + w_{t+i} H_{t+i}(k)) \right] \tag{9}$$

where the demand for an intermediate good k from final-goods firms has been substituted. It is important to note that the price chosen by the firm in period t is independent from the price chosen in $t+n$, so future price adjustments are not taken into account in the optimization problem. For the firm, this problem is dual to minimizing total real costs in each period. The solution to such a problem would be the demand for labor and capital by intermediate firms, which along the demand function for intermediate goods can be substituted into expression (9) to yield the intertemporal profit function for the household. The real cost minimization problem is given by

$$\min_{K_{t+i}(k), H_{t+i}(k)} \quad r_{t+i} K_{t+i}(k) + w_{t+i} H_{t+i}(k) \tag{10a}$$

$$\text{subject to} \quad Y_{t+i}(k) = z_t K_{t+i}^{\theta}(k) H_{t+i}^{1-\theta}(k) \tag{10b}$$

$$\tag{10c}$$

The Lagrangian for this problem can be written as

$$\mathcal{L} = r_{t+i} K_{t+i}(k) + w_{t+i} H_{t+i}(k) + \Theta_{t+i} \left[Y_{t+i}(k) - z_{t+i} K_{t+i}^{\theta}(k) H_{t+i}^{1-\theta}(k) \right] \tag{11}$$

The first order conditions are given by

$$\frac{\partial \mathcal{L}}{\partial K_{t+i}(k)} = r_{t+i} + \Theta_{t+i} z_{t+i} \theta K_{t+i}^{\theta-1}(k) H_{t+i}^{1-\theta}(k) = 0 \tag{12}$$

$$\frac{\partial \mathcal{L}}{\partial H_{t+i}(k)} = w_{t+i} + \Theta_{t+i} z_{t+i} (1-\theta) K_{t+i}^{\theta}(k) H_{t+i}^{-\theta}(k) = 0 \tag{13}$$

Dividing both conditions and rearranging, the equilibrium condition resulting from this problem can be wrtitten as

$$\frac{(1-\theta)r_{t+i}}{\theta w_{t+i}} = \frac{H_{t+i}(k)}{K_{t+i}(k)} \tag{14}$$

Rearranging this expression in terms of the inputs and substituting it in the production function, one obtains the demands for labor as

$$H_{t+i}(k) = \frac{Y_{t+i}(k)}{\lambda_{t+i}} \left[\frac{r_{t+i}(1-\theta)}{w_{t+i}\theta} \right]^{\theta} \tag{15}$$

and the demand for capital as

$$K_{t+i}(k) = \frac{Y_{t+i}(k)}{\lambda_{t+i}} \left[\frac{r_{t+i}(1-\theta)}{w_{t+i}\theta} \right]^{theta-1} \tag{16}$$

Substituting this expressions into the real cost expression, we obtain the total cost function

$$C_{t+i} = r_{t+i} \frac{Y_{t+i}(k)}{\lambda_{t+i}} \left[\frac{r_{t+i}(1-\theta)}{w_{t+i}\theta} \right]^{\theta-1} + w_{t+i} \frac{Y_{t+i}(k)}{\lambda_{t+i}} \left[\frac{r_{t+i}(1-\theta)}{w_{t+i}\theta} \right]^{\theta} \tag{17}$$

Differentiating with respect to Y_{t+i}, we obtain an expression for marginal costs given by

$$MC_{t+i} = \frac{w_{t+i}}{(1-\theta)\lambda_{t+i}} \left[\frac{r_{t+i}(1-\theta)}{\theta w_{t+i}} \right]^{\theta} \tag{18}$$

The optimization problem for the firm can thus be rewritten as

$$\max_{P_t^*(k)} E_t \sum_{j=0}^{\infty} (\beta\rho)^i Y_{t+i} \left(\frac{P_{t+i}}{P_t^*(k)} \right)^{\psi} \left[P_t^*(k) - \frac{P_{t+i} w_{t+i}}{(1-\theta) z_{t+i}} \left[\frac{r_{t+i}(1-\theta)}{\theta w_{t+i}} \right]^{\theta} \right] \tag{19}$$

The first order condition is given by

$$E_t \sum_{j=0}^{\infty} (\beta\rho)^i Y_{t+i}(k) \left[1 - \psi + \frac{\psi P_{t+i} w_{t+i}}{P_t^*(k)(1-\theta)\lambda_{t+i}} \left[\frac{r_{t+i}(1-\theta)}{\theta w_{t+i}} \right]^{\theta} \right] = 0 \tag{20}$$

rearranging in terms of the optimal price that a firm k chooses if it can set its price in t yields

$$P_t^*(k) = \frac{\psi}{\psi - 1} \frac{E_t \sum_{j=0}^{\infty} (\beta\rho)^i P_{t+i} Y_{t+i}(k) \frac{w_{t+i}}{(1-\theta)\lambda_{t+i}} \left[\frac{r_{t+i}(1-\theta)}{w_{t+i}\theta} \right]^{\theta}}{E_t \sum_{j=0}^{\infty} (\beta\rho)^i Y_{t+i}(k)} \tag{21}$$

which is the pricing rule for firms in the intermediate goods sector. In this expression, $\frac{\psi}{\psi-1}$ is defined as the markup that firms charge over marginal cost[16]. In this case, prices at the aggregate level will evolve according to

$$P_t^{1-\psi} = \rho P_{t-1}^{1-\psi} + (1-\rho)(P_t^*)^{1-\psi} \tag{22}$$

That is, the price level in period t will be a weighted average between the price level in $t-1$ and the optimal price chosen by firms that can readjust prices in t, with the weight being the fraction of firms that cannot readjust prices.

3.2 Households

A unit mass of households choose a combination of consumption and leisure that maximizes expected lifetime utility. These are heterogenous in the sense that they supply a differentiated labor service to firms. Because the labor service of each family is different, firms consider the labor service of each family as imperfect substitutes of the labor service provided by every other family. Thus, families have power to set their wage over the marginal rate of substitution between consumption and leisure. Wage rigidity is introduced into our model via staggered wage contracts. In particular, families sign contracts with a representative labor aggregator (such as an employment agency or a union) in which they accord a fixed nominal wage from the time the contract is signed until the time period when the contract expires. The intertemporal optimization problem solved by households can be expressed as

[16] More specifically, the ratio of price over the discounted stream of nominal costs divided by the discounted stream of real output (McCandless, 2008).

$$\max \quad E_t \sum_{j=0}^{\infty} \beta^j [\ln c^i_{t+j} + A \ln(1 - h^i_{t+j})] \tag{23a}$$

$$\text{subject to} \quad P_{t+j} c^i_{t+j} = m^i_{t-1+j} + (g_{t+j} - 1) M_{t-1+j} \tag{23b}$$

$$k^i_{t+1+j} + \frac{m^i_{t+j}}{P_{t+j}} = \frac{W(i)_t}{P_{t+j}} h^i_{t+j} + r_{t+j} k^i_{t+j} + (1-\delta) k^i_{t+j} + b^i_{t+j} + \Pi_{t+j} \tag{23c}$$

where equation (23a) is the objective function for households. Equation (23b) corresponds to a sequence of cash in advance constraints (Cooley and Hansen, 1958). In period t, household i holds an amount of money carried over from the previous period and receives a transfer[17] from the government or monetary authority equal to $(g_t - 1)M_{t-1}$, where g_t is the growth rate of transfers to households in period t. This growth rate is determined exogenously by the government, and evolves as

$$\ln g_{t+1} = \pi \ln g_t + \epsilon^g_{t+1} \tag{24}$$

where π is the degree of persistence of changes in monetary transfers and ϵ^g_{t+1} is an unanticipated monetary growth shock with $\epsilon^g_{t+1} \sim (0, \sigma^2)$. If it were dated at t, then it would be anticipated. M_t is the per-capita money stock at $t-1$, but because we assume that there is a unit mass of households, the per-capita values are equal to the aggregate values of the same variable in our model. Thus, in equilibrium, the cash in advance constraint simplifies to

$$P_t C_t = g_t M_{t-1} \tag{25}$$

Equation (23c) corresponds to a sequence of flow budget constraints, which establishes that households earn income from labor by working h_t hours and receiving a nominal wage of $W^i_t(i)$, from renting capital services k_t to firms at rental rate r_t, from the wage insurance premium or payout stipulated in the wage contract b_t and from excess profits firms can make and pay out as dividends, Π_t. Similar to the demand for intermediate goods by firms

[17] It is important to note that I assume that the transfer made to a household does not depend on that particular household's holding of money.

in the final goods market, the demand for labor of any family i by firms is given by

$$h_t^i = H_t \left[\frac{W_t}{W_t^*(i)} \right]^{\psi_w} \tag{26}$$

where aggregate hours worked H_t is given by the technology by which firms combine different types of labor to produce final goods, which takes the form

$$H_t = \left(\int_0^1 h_t^{i \, \frac{\phi_w - 1}{\phi_w}} di \right) \tag{27}$$

The intertemporal optimization problem for a household i can be rewritten as

$$\begin{aligned} \mathcal{L} = E_t \sum_{j=0}^{\infty} (\beta \rho_w)^j [\ln c_{t+j}^i + A \ln(1 - h_{t+j}^i)] \\ + \lambda_{t+j}^1 [P_{t+j} c_{t+j}^i - m_{t+j-1}^i - (g_{t+j} - 1) M_{t+j-1}] \\ + \lambda_{t+j}^2 \left[k_{t+j+1}^i + \frac{m_{t+j}^i}{P_{t+j}} - \frac{W_t^*}{P_{t+j}} H_{t+j} \left(\frac{W_t}{W_t^*(i)} \right)^{\psi_w} - r_{t+j} k_{t+j}^i - (1 - \delta) K_{t+j}^i - b_{t+j}^i \right] \end{aligned} \tag{28}$$

with consumption, money holdings and the capital to be carried into next period as the control variables for the household in period t. Hence, the first order conditions in period t are given by

$$\frac{\partial \mathcal{L}}{\partial c_t} = \frac{1}{c_t^i} + \lambda_t^1 P_t = 0 \tag{29}$$

$$\frac{\partial \mathcal{L}}{\partial m_t} = -E_t \beta \lambda_{t+1}^1 + \lambda_t^2 \frac{1}{P_t} = 0 \tag{30}$$

$$\frac{\partial \mathcal{L}}{\partial m_t} = \lambda_t^2 - \beta E_t \lambda_{t+1}^2 (r_{t+1} + (1 - \delta)) = 0 \tag{31}$$

Rearraning the first and second expressions in terms of the Lagrange multipliers and substituting these into the third expression, the equilibrium condition for households (usually referred to as the Euler equation) is obtained as

$$E_t \frac{P_t}{P_{t+1} c^i_{t+1}} = \beta E_t \frac{P_{t+1}}{P_{t+2} c^i_{t+2}} (r_{t+1} + (1 - \delta)) \tag{32}$$

Finally, a family that gets to set its nominal wage in period t will choose a nominal wage that maximizes

$$\begin{aligned} \mathcal{L} = E_t \sum_{j=0}^{\infty} (\beta \rho_w)^j \left[\ln c^i_{t+j} + A \ln \left(1 - H_{t+j} \left(\frac{W_{t+j}}{W^*_t(i)} \right) \right) \right] \\ + \lambda^1_{t+j} [P_{t+j} c^i_{t+j} - m^i_{t+j-1} - (g_{t+j} - 1) M_{t+j-1}] \\ + \lambda^2_{t+j} \left[k^i_{t+j+1} + \frac{m^i_{t+j}}{P_{t+j}} - \frac{W^*_t}{P_{t+j}} H_{t+j} \left(\frac{W_t}{W^*_t(i)} \right)^{\psi_w} - r_{t+j} k^i_{t+j} - (1 - \delta) K^i_{t+j} - b^i_{t+j} \right] \end{aligned} \tag{33}$$

where we have substituted the demand for labor by final goods firms. Now, the first oder condition is given by

$$\begin{aligned} \frac{\partial \mathcal{L}}{\partial W^*_t(i)} = E_t \sum_{j=0}^{\infty} (\beta \rho_w)^j \Bigg[A \frac{1}{1 - H_{t+j} \frac{W_{t+j}}{W^*_t(i)}^{\psi_w}} \left(\frac{W_{t+j}}{W^*_t(i)} \right)^{\psi_w} \frac{\psi_w H_{t+j}}{W^*_t(i)} \\ + \lambda^2_{t+j} \left[(\psi_w - 1) \frac{H_{t+j}}{P_{t+j}} \left(\frac{W_{t+j}}{W^*_t(i)} \right)^{\psi_w} \right] \Bigg] = 0 \end{aligned} \tag{34}$$

Rearranging the first order conditions given by (29) and (30) in terms of the Lagrangian multipliers and substituting into (34), one obtains a wage setting rule of

$$W^*_t(i) = \frac{\psi_w}{\psi_w - 1} \frac{A}{\beta} \frac{E_t \sum_{j=0}^{\infty} (\beta \rho_w)^j \frac{1}{1 - h^i_{t+j}} h^i_{t+j}}{E_t \sum_{j=0}^{\infty} (\beta \rho_w)^j \frac{1}{P_{t+1+j} c^i_{t+1+j}} h^i_{t+j}} \tag{35}$$

As already highlighted, in every period, there will be families that will not be able to adjust their wages freely. In the aggregate, nominal wages will evolve according to

$$W_t = [(1-\rho_w)(W_t^*)^{1-\psi_w} + \rho_w(W_{t-1})^{1-\psi_w}]^{\frac{1}{1-\psi_w}} \quad (36)$$

Thus, aggregate wages in t will be determined by a weighted average between the aggregate nominal wage in $t-1$ and the optimal wage that families choose if they get to readjust them in period t, $W_t^* = W_t^*(i)$ with the weight being ρ_w, the fraction of individuals whose wage contract expires and can adjust their nominal wage to the optimal nominal wage in t.

3.3 Calibration

To solve our model and find the policy functions using a numerical technique, it is important to fix the values of our model parameters. In this paper, I estimate some of the model parameters, while I calibrate others. The assigned values to some of the model parameters must be consistent with empirical observations at the aggregate and micro level. Particularly, these should be consistent with long run growth observations (stylized facts) and microeconomic evidence regarding household preferences. This process is known as calibration (Gomme and Lkhagvasuren, 2012).

We calibrate our parameter values from various sources. Table 1 presents the parameters to be calibrated along with the assigned values in the calibration process. For instance, the parameter θ, corresponding to the fraction of capital used for production purposes, is calibrated as the fraction of national income that is paid to capital services[18], in line with Kydland and Prescott (1982). From fiscal year 1980 to fiscal year 2019, this proportion assumed a mean value of 0.327, which is the value we assign to θ. The deppreciation rate δ is calibrated at 0.031, which is the mean value of the calculated deppreciation rate in the Island from fiscal year 1980 to fiscal year 2019[19].

[18]The fraction of national income received by labor services is calculated as the sum of compensations to employees and propietary income, divided by the sum of the gross national product, deppreciation and indirect taxes. This series are obtained from the Statistical Appendix of the Economic Report to the Governor, produced by the Planning Board.

[19]The deppreciation rate is calculated as real deppreciation of capital divided the real capital stock. The capital stock series for the Island is estimated using the recursive expression

$$k_{t+1} = (1-\delta)k_t + i_t = k_t + (i_t - \textbf{Real Deppreciation}_t) \quad (37)$$

with the initial value being gross domestic fixed investment in 1940, which is the oldest observation available for the investment series in the Island.

The parameter β, corresponding to the discount factor of households, is calibrated at 0.99, a value frequently used in the literature and in line with Kydland and Prescott (1982), Hansen (1985) and McCandless (2008). The parameters ψ and ψ_w, corresponding to markups of price over marginal cost and of wage over marginal rate of substitutition, are both calibrated at 11, respectively, implying markups of 10 percent in the steady state.

Table 1: **Calibrated Parameters**

Parameter	β	δ	θ	ψ	ψ_w
Calibrated Values	0.99	0.031	0.0327	11	11

4 Estimation Methodology

In this section, I present the empirical strategy employed to obtain estimates of the remaining parameters in the model. There are several techniques for estimating the parameters of DSGE models, with most of these techniques based on frequentist and bayesian approaches. Christiano and Eichenbaum (1992) estimate the parameters of a real business cycle model using the technique known as Generalized Method of Moments (GMM). Altug (1989), McGrattan (1994), Kim (2000) and Irland (2000) are examples of the application of the Full-Information Maximum Likelihood method to estimate the parameters of medium to large scale DSGE models. Such a method is amongst the most popular frequentist methods of estimation in the DSGE literature.

This paper employs bayesian techniques as in Schorfheide (2000) and Smets and Wouters (2007) to generate estimates for our remaining model parameters[20]. In contrast to the frequentist approach, which establishes that parameters of interest are fixed but unkown quantities, the Bayesian approach is based on the notion that parameters can have a variability which can be explained by a probability distribution (Casella and Berger, 2012; Alemar and Rodríguez, 2019). This distribution is often referred to as the prior distribution of the parameter.

For the purpose of this work, the Bayesian approach has two main advantages. First,

[20]Other relevant contributions that employ this technique are those of Dejong et.al (2000), Otrok (2001), Lubik and Schorfheide (2005), Onatski and Williams (2004) and Adolfson et. al (2008).

the Bayesian approach responds to the Lucas (1976) critique, which states that the parameters of economic relationships in the aggregate are not constant over time, but vary according to the implementation of distinct policies. By assuming that parameters are not constant over time and that they vary according to a probability distribution, the Bayesian approach presents a direct solution to the problem outlined by Lucas in his critique. Second, a complete characterization of the uncertainty sorrounding the estimated parameters can be achieved through the construction of credibility intervals for such parameters (Elekdag, Justiniano and Chakarov, 2006). When simulating the effects of the shocks of interest on the model economy, these credibility intervals will be useful in determining the sufficiency of evidence in favor of the simulated effects of such shocks.

The Bayesian approach consists in updating information regarding our model parameters, summarized by their prior distribution, based on an observed sample of data. Such a process yields an updated distribution for our parameters reflecting the observed data, known as the posterior distribution. Once this posterior distribution has been obtained, estimates of our model parameters can be generated by taking samples from this distribution using a particular sampling algorithm. The parameters can then be estimated by taking the first moment of this distribution and averaging it over all of the samples. For the purpose of this work, we use the Metropolis Hastings algorithm to sample from the posterior and generate estimates for our model parameters. For a sufficiently high number of replications of our sampling algorithm, the estimated average over all samples converges to the parameter of interest by the Weak Law of Large Numbers. Addiditionally, by the Central Limit Theorem, the precision of the approximations of the average increases as the sample size is increased (Schorfheide, 2000).

4.1 Bayesian Updating of Parameter Knowledge

When new observations of variables that are related in a specific form to other variables in our model are made available in a given period t, these are included in the information set and the previous knowledge that we had before such information was available (the prior distribution) is updated. As highlighted before, this process yields the posterior distribution of the parameters. Formally, let Θ be the vector that contains the parameters to be estimated and Φ a vector that contains the calibrated parameters. The parameter vector Θ takes the form

$$\Theta = [\rho, \rho_w, \gamma, \pi, \sigma_z, \sigma_g] \tag{38}$$

The information set in period t, X_t, contains a set of historical macroeconomic time series related to the variables in our model. It includes the observed values for the series in period t and past observations, namely $X_t = \{y_t^{obs}, X_{t-1}\}$. Knowledge about the parameters in advance of the observation of data in t and conditional on past observed data is summarized by the prior distribution $P(\Theta|X_{t-1}, \Phi)$. Thus, by Bayes' theorem, the posterior distribution is characterized as

$$P(\Theta|X_t, \Phi) = \frac{P(X_t|\Theta, \Phi)}{P(X_t)} P(\Theta|X_{t-1}, \Phi) \tag{39}$$

Where $P(X_t, \Phi|\Theta)$ is the likelihood function for the parameters conditional on the observed data in t and $P(X_t)$ is the marginal distribution, defined as

$$P(X_t) = \int P(X_t|\Theta, \Phi) P(\Theta|X_{t-1}, \Phi) d\Theta$$

which is defined so that it integrates to 1. In particular, the posterior distribution can be written as

$$P(\Theta|X_t, \Phi) \propto P(X_t|\Theta, \Phi) P(\Theta|X_{t-1}, \Phi) \tag{40}$$

Thus, once the likelihood function is evaluated and prior distributions have been defined, the characterization of the posterior distribution is completed by proportionality.

4.2 State-Space Representation

Our model can be represented in state-space form as

$$y_t^{obs} = C_0 + C_1 S_t + v_t \tag{41}$$

$$S_t = \Gamma(\Theta, \Phi) S_{t-1} + \Gamma_\epsilon(\Theta, \Phi) \epsilon_t \tag{42}$$

where y_t^{obs} is the vector of variables for which data is observed and S_t is a vector of the variables in our model in log-linear form. This includes their expectations, which are not observed. For our model, this vector is defined as

$$S_t = [\hat{C}_t, \hat{R}_t, \hat{W}_t, \hat{Y}_t, \hat{H}_t, \hat{K}_{t+1}, \hat{z}_t, \hat{g}_t, \hat{P}_t, \hat{M}_t, E_t\hat{P}_{t+1}, E_t\hat{C}_{t+1}, E_t\hat{g}_{t+1}, E_t\hat{M}_{t+1}, E_t\hat{R}_{t+1}, E_t\hat{W}_{t+1}] \tag{43}$$

where $\hat{x}_t$ represents the percentage deviation of the variable x_t from its steady state value[21]. Equation (41) is the measurement equation for the observed variables in our model, where C_1 is a matrix linking the variables for which data is observed and the model variables, C_0 contains the mean of the stationary observed variables and v_t is a measurement error with mean zero and positive semi-definite variance-covariance matrix. This measurement error captures the fluctuations in the observed variable that are not explained by fluctuations in the model variables due to possible measurement errors in the observed data. According to Del Negro and Schorfheide (2009) and Pfeifer (2014), the inclusion of measurement errors in the state-space model can be a solution to possible misspecification when the data violates the restrictions implied by the model equations.

Equation (42) represents the rational expectations solution to our log-linear model. In particular, the technique used to solve the model numerically and obtain this solution is that of Blanchard and Kahn (1980). The matrices $\Gamma(\Theta, \Phi)$ and $\Gamma_\epsilon(\Theta, \Phi)$ are functions of our model parameters, and ϵ_t is the vector of structural shocks in our model, namely $\epsilon_t = [\epsilon_t^z, \epsilon_g]$.

[21] In particular, we use the method of log-linearization proposed by Uhlig (1995). A variable x_t can be written as $x_t = x_{ss} \exp \hat{x}_t$. Taking logarithms on both sides, we have

$$\ln x_t = \ln x_{ss} + \hat{x}_t \tag{44}$$

rearranging,

$$\hat{x}_t = \ln x_t - \ln x_{ss} \tag{45}$$

which is the percentage deviation of the variable from its steady state value.

4.3 Evaluation of the Likelihood Function

Given that the variables in our model are partially not observed and these define the likelihood function, it is not possible to evaluate this function analytically (Schorfheide, 2015). Nonetheless, if the measurement error v_t, the vector of structural shocks ϵ_t and the initial state of the model S_0 are independent and identically distributed normal variables, then the Kalman Filter algorithm can be used to evaluate the likelihood function. With this, the posterior distribution would be completely characterized. In particular, the Kalman Filter generates a sequence of marginal densities $P(y_t|X_{t-1}, \Theta, \Phi)$ from which the desired likelihood function can be obtained by generating period-by-period proyections of the state-space system (Guerrón and Quintana, 2012). Thus, the desired likelihood function for the log-linearized model can be obtained as

$$P(X_t, \Phi|\Theta) = P(y_t, X_{t-1}, \Phi|\Theta) = \prod_{t=1}^{T} p(y_t|X_{t-1}, \Theta, \Phi) \tag{46}$$

By combining this likelihood function with a defined prior distribution, the characterization of the posterior distribution is complete and estimates for the model parameters can be generated by sampling from this distribution with a sampling algorithm. I now discuss the sampling algorithm employed in this work.

4.4 Sampling from the Posterior with the Random-Walk Metropolis Hastings Algoritm

Once the posterior is obtained, we can generate samples from it through the Random-Walk Metropolis Hastings (RWMH) Algorithm. In particular, its name comes from the law of motion of the generated samples,

$$\Theta_l = \hat{\Theta}_{l-1} + u_l \tag{47}$$

which states that generated random samples follow a random walk process. In particular, Θ_l is a proposed update for the sample Θ_{l-1} and $u_l \sim I.I.DN(0_{kx1}, c^2\Sigma_l)$, where k is the number of parameters to be estimated. From equation (47), it can be verified that $E[\Theta_l] = \Theta_{l-1}$ and $Var(\Theta_l) = Var(u_l) = c^2\Sigma_l$. Thus, the mean of the proposed distribution is the location of the chain and its variance is augmented by a scale factor of c. This scale factor can be adjusted so as to control the proportion of samples that are accepted by the algorithm for updating.

The sampling algorithm can be summarized in the following steps (Guerrón and Quintana, 2012):

1. Select an initial value Θ_0 to initialize the MH algorithm. This value is determined as the mode of the posterior distribution that results in a maximum value for the logarithm of the posterior, and is obtained by a numerical routine[22] to optimize the likelihood.

2. Using the Kalman Filter, evaluate the likelihood function on this initial vector Θ_0. This will generate an initial estimate of $P(X_t|\Theta_0, \Phi)$ for the likelihood.

3. An update Θ_1 is proposed for $\hat{\Theta}_0$. This proposed update takes the form $\Theta_1 = \hat{\Theta}_0 + u_1$, and the Kalman filter can be used to obtain the likelihood $P(X_t|\Theta_1, \Phi)$.

4. The algorithm accepts Θ_1 as an update with a probability given by

$$\alpha = min\left\{\frac{P(X_t|\Theta_1, \Phi)P(\Theta_1)}{P(X_t|\hat{\Theta}_0, \Phi)P(\hat{\Theta}_0)}, 1\right\} \tag{48}$$

where it should be noted that $P(\Theta_l|X_t, \Phi) = P(X_t|\Theta_l, \Phi)P(\Theta_l)$. Thus, if the proposed update increases the value of the posterior density, then $P(\Theta_1|X_t, \Phi) > P(\Theta_0|X_t, \Phi)$ and the update is accepted ($\alpha = 1$). According to Roberts, Gelman and Gilks (1997), the optimal acceptance rate for the proposed updates for the samples should be between 20 percent and 30 percent. In this work, we adjust the scale factor c to attain an acceptance rate for our proposed updates in such a range under each chain of the algorithm.

From the random samples generated by this algorithm, which take the form $\{\Theta_l\}_{l=1}^{N}$, parameter estimates can be obtained by averaging their first moment over all samples (Elekdag, et.al., 2006). In particular, the number of generated samples N is chosen so as to achieve convergence of the simulator. As the number of replications of the algoritm (number of samples) increases, the Central Limit Theorem secures precision of the approximation of the posterior distribution. Thus, when the simulation converges, a sample taken from the Markov Chain will have approximately the same distribution as a sample that is taken

[22]We employ the routine of Christopher Sims in this work, which can be downloaded from sims.princeton.edu/yftp/optimize/.

directly from the posterior (Schorfheide, 2015).

4.5 Data and Measurement

In this section, I provide a description of the data used in the estimation of our remaining parameters. I also specify measurement equations relating the variables for which we observe data to the model variables. The observed data series consist of the quarterly growth in inflation, output and real wages in Puerto Rico from 1980Q1 to 2019Q1. Given that quarterly national accounts are not produced in Puerto Rico, the quarterly data series were obtained by interpolation of the annual series. In particular, the quarterly output series were obtained by applying the interpolation methodology proposed by Alameda[23] (2007). The quarterly inflation and real wage series are obtained by interpolating the annual series with a local quadratic average matched to the source data[24]. These annual series were obtained from the Statistical Appendix of the Economic Report to the Governor, produced by the Planning Board of Puerto Rico. The quarterly nominal wage growth and inflation series are plotted in Figure 1, while real output growth is plotted in figure 2.

As can be seen in figure 1, inflation and nominal wage growth were growing at similar and modest rates until 2005. Nonetheless, nominal wages have been more volatile than inflation, and more recently, inflation has been higher than nominal wage growth. Since 2005Q2, nominal wage growth has stagnated, with a lower average growth rate after 2005. This behavior is not exclusive of wages, as inflation can be seen to have a lower mean as well after 2011. Such differences in average growth rates can be a sign of non-stationarity of the series. This would imply that the nominal wage and price level series would be I(2), something that is partially confirmed by unit root tests performed on the variables[25]. Thus, the observation equations specified for inflation and real wages are given by

$$d\ln\frac{W_t^{obs}}{W_{t-1}^{obs}} = \hat{W}_t - 2\hat{W}_{t-1} + \hat{W}_{t-2} + \gamma_W + v_t^W \tag{49}$$

[23]This methodology consists in estimating a regression of annual real GNP on an Economic Activity Index. Then, the quarterly output series can be estimated by multiplying by the estimated regression coefficient by the quarterly series of the Index. We use the Economic Activity Index produced by the Economic Development Bank and estimate our regression via the Johansen cointegration method.

[24]The interpolations, including that of the output series, are performed in the EViews platform.

[25]The augmented Dickey-Fuller unit root test was used. See appendix.

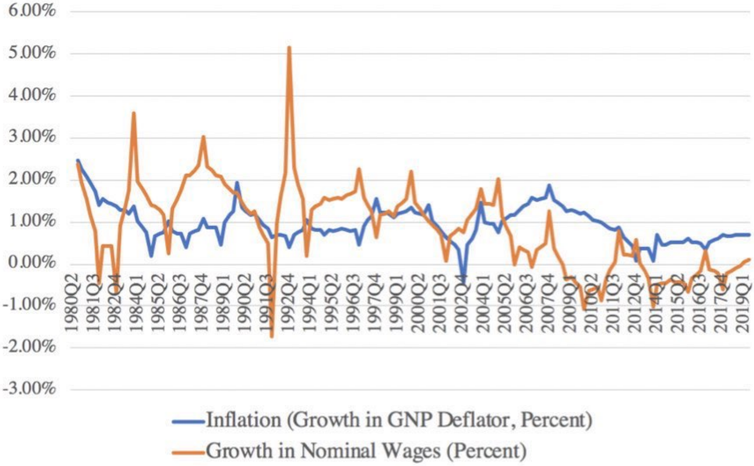

Figure 1: **Quarterly Inflation and Nominal Wage Growth in Puerto Rico**. The orange line depicts denotes the growth rate of nominal wages, while the blue line depicts inflation rate as measured by the growth rate in the GNP deflator, from 1980Q1 to 2019Q1. Source: Own elaboration.

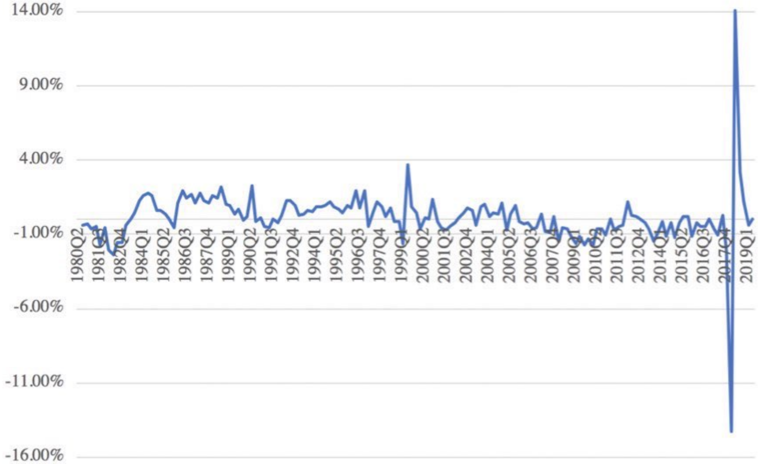

Figure 2: **Quarterly Real Output Growth in Puerto Rico**. The blue line depicts the growth rate of real output as measured by quarter-to-quarter first differences in the logarithm of real GNP, from 1980Q1 to 2019Q1. Source: Own elaboration.

$$d \ln \frac{P_t^{obs}}{P_{t-1}^{obs}} = \hat{P}_t - 2\hat{P}_{t-1} + \hat{P}_{t-2} + \gamma_P + v_t^P \tag{50}$$

and the observation equation for output growth is given by

$$\ln \frac{Y_t^{obs}}{Y_{t-1}^{obs}} = \hat{Y}_t - \hat{Y}_{t-1} + \gamma_Y + v_t^Y \tag{51}$$

where d stands for the difference operator. The $\gamma' s$ are the (constant) means of the stationary series. Thus, our observables vector in the state-space representation given by equations (41)-(42) takes the form $y_t = \left[d \ln \frac{W_t^{obs}}{W_{t-1}^{obs}}, d \ln \frac{P_t^{obs}}{P_{t-1}^{obs}}, \ln \frac{Y_t^{obs}}{Y_{t-1}^{obs}} \right]$, while the measurement error vector takes the form $v_t = [v_t^W, v_t^P, v_t^Y]$.

4.6 Selection of Priors

Prior distributions are selected by introspection so as to achieve realistic bounds for our model parameters (Schorfheide, 2000). Our particular objective is to select priors that are as non-informative as possible.

As highlighted by Iskrev (2018), some parameters may be difficult to identify based on the available observed data or because there is already a consensus in the literature regarding those particular parameter values. In order to avoid identification problemas along such lines, in this paper I estimate some parameters while I calibrate others, as previously highlighted.

The parameters to be estimated are those corresponding to the degrees of price and wage rigidities, ρ and ρ_w, those corresponding to the degrees of persistence of the technology and monetary shocks, γ and π, and the standard deviation of the structural shocks and measurement errors, namely σ_z, σ_g, σ_y, σ_w and σ_P.

In particular, I choose non-informative priors for all of the parameters in order for the data to have the strongest possible weight in the estimation. For the degrees of nominal rigidities and the degrees of persistence of structural shocks, I select a Beta distribution with mean 0.5 and standard deviation of 0.15, respectively. These parameters should be less than 1 in order to ensure model stability[26]. Thus, the Beta distribution is an ideal prior given that it restrics the parameters to assume values in the $[0, 1]$ interval. For the parameters related to the standard errors of shocks, I select inverse-gamma distributions with mean of 0.01 and standard deviation of 4. According to Gelman (2006), this distribution is frequently assigned as a prior for standard deviations due to its lack of informativeness in the estimation.

Table 2 presents a list of the parameters to be estimated along with their selected prior distributions.

[26] In particular, higher prior standard deviations result in the log-posterior covering areas of the parameter region where the model becomes explosive. Thus, the variance-covariance matrix will not be positive semi-definite and the model will not be solvable under the estimated parameters and credibility intervals.

Table 2: **Selected Prior Distributions for Parameters to be Estimated**

Parameter	Prior Distribution	Prior Mean	Prior S.D
ρ	Beta	0.5	0.15
ρ_w	Beta	0.5	0.15
γ	Beta	0.5	0.2
π	Beta	0.5	0.2
σ_z	Inverse-Gamma	0.01	4
σ_g	Inverse-Gamma	0.01	4
σ_Y	Inverse-Gamma	0.01	4
σ_W	Inverse-Gamma	0.01	4
σ_P	Inverse-Gamma	0.01	4

5 Results

In this section, we present and discuss the results from the estimation of the model. These estimates are obtained by generating 400,000 samples from the posterior distribution through the MCMC algorithm in the Dynare program. Such a number of generated samples is sufficient to ensure the convergence of the estimates. We run two Markov chains of 400,000 replications. As suggested by Gelman (2006), the scale factor is adjusted so as to achieve an acceptance rate of 20% to 40% of the proposed updates for the parameters.

In the next subsection, we discuss the results of our parameter estimates, paying special attention to the average degrees of price and wage rigidity. We later analyze the implications of these estimated degrees of rigidity for aggregate fluctuations. In our model, the sources of fluctuations around the long term growth trend are the technology and monetary transfer growth shocks. Thus, I simulate the impact of each of these shocks under the estimated degres of rigidity. The result of this exercise are the impulse-response functions (IRF's). I then perform a stability analysis of the estimated parameters over time by estimating the model in two sub-periods. These two sub-periods are 1980-2000 and 2001-2019. Finally, I present concluding remarks and discuss policy implications.

5.1 Parameter Estimates

Table 3 presents the posterior estimates of our parameters along with the lower and upper limits of a 90% Bayesian credibility interval for the estimates.

First, I examine the estimates corresponding to the average degrees of price and wage ridigity. For each value of this parameter, there is an associated frequency (duration) of price and nominal wage change in the economy. Particularly, Sims (2017) shows that if $1 - \rho$ is the probability that prices are adjusted in any period, then $\frac{1}{1-\rho}$ is the expected duration of prices from the period these are set by firms until they are readjusted. We use this expression to estimate the average frequency of price and wage change or readjustment from our estimated degrees of rigidity. The higher the estimated degrees of nominal rigidity in the economy (share of firms or individuals that cannot adjust their prices or wages in any given period), the longer will be the duration of the prices or wages set in any given period. Thus, high degrees of price/wage rigidity imply prices/wages change at a much lower frequency.

Table 3: **Posterior Parameter Estimates**

Parameter	**Estimated Posterior Mean**	**90% (Lower)**	**10% (Upper)**
ρ	0.79	0.69	0.9
ρ_w	0.64	0.47	0.82
γ	0.32	0.14	0.5
π	0.39	0.22	0.56
σ_z	0.005	0.002	0.007
σ_g	0.004	0.002	0.005
σ_Y	0.017	0.015	0.02
σ_W	0.0066	0.006	0.007
σ_P	0.0022	0.0019	0.0025

As can be seen from the first row of Table 3, the parameter corresponding to the average degree of price rigidity is estimated at 0.79, with a 90% credibility interval ranging from 0.69 to 0.9. This yields an average frequency of price change equal to 4.76 quarters, implying that, on average, prices in the economy change every 14 months, with a credibility interval ranging from 9 to 30 months. Compared to an estimate of 0.64 for the average degree of wage rigidity, which translates to an average frequency of change of 8 months for nominal wages, this implies that prices can take up to 5 more months to readjust after wages have readjusted. Another interpretation is that, on average, a larger fraction of firms do not readjust their prices in any given period relative to the fraction of individuals that have to readjust their nominal wages. Thus, prices readjust less often than nominal wages. This implies that prices, on average, take longer to readjust than nominal wages following a shock that causes the economy to deviate from its long run trend.

Table 4: **Calvo price rigidity parameter: Estimates obtained for Puerto Rico vs estimates for the United States in the literature**

Study	Calvo price rigidity estimate
US - Christiano et. al. (2005)	0.6
US - Smets and Wouters (2007)	0.66
US - Ascari et. al. (2010)	0.59
US - Guerrón Quintana and Nason (2012)	0.65
Puerto Rico - Estimate obtained	0.79

Moreover, our estimate of 0.79 for the average degree of price rigidity (average fraction of firms that do not adjust their prices in any given period) is greater than previous estimates of this parameter obtained for the US economy after 1980, as Table 4 shows. These estimates for the US were obtained using the same model structure, priors for the parameters and in the same timeframe, so as to ensure comparability between the estimates in average terms. This implies an average duration of prices that is 21% to 34% longer in Puerto Rico than in the United States. Figure 3 shows the implied average quarterly duration of prices derived from the Calvo parameter estimates obtained for Puerto Rico vs. for the United States in previous studies. As can be seen, our estimate implies that prices can take up to 2 more quarters on average to adjust in Puerto Rico. Thus, this constitutes evidence that, on average, prices change with less frequency in Puerto Rico, and are thus more rigid, than in the United States.

Nonetheless, it is important to point out that the responses of prices and wages can be assymetric with respect to the sign of the shock. In general, the consensus is that prices tend to be more rigid downwards than upwards, which implies that the response of prices and wages to a shock that puts downward pressure on them will imply higher degrees of rigidity (closer to the upper bound of the estimated credibility interval). Thus, we focus mainly on shocks that put downward pressure on prices, namely positive technology shocks and negative policy-induced demand shocks. Analogously, for shocks that put upward pressure on prices and wages, the degree of rigidity will be lower (closer to the lower bound of the credibility interval).

With respect to the remaining parameters, the degrees of persistence of the technology shock, γ, is estimated at 0.32, while that of the money transfer growth shock, π, is estimated at 0.39. This constitutes evidence that the effects of a shock to the growth of monetary

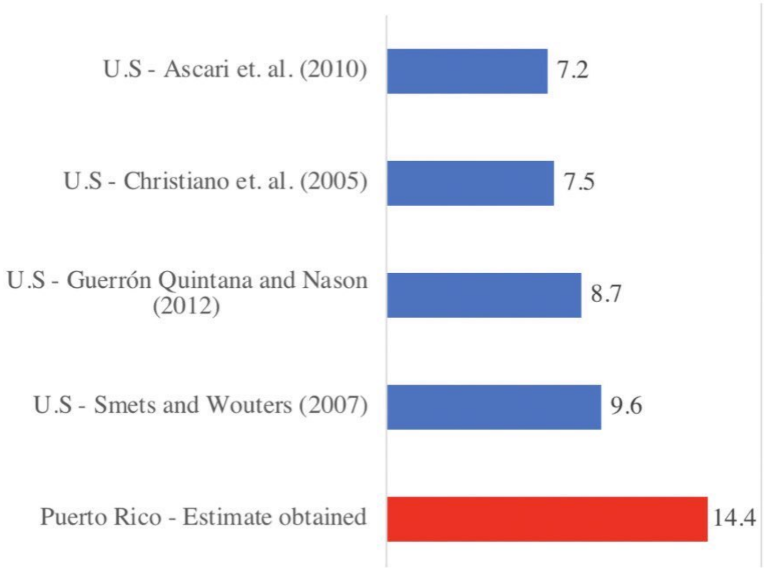

Figure 3: **Average implied duration of prices (in months): Estimate obtained for Puerto Rico vs estimates for the United States in the literature**

transfers tend to be more persistent over time than those of the technology shock. The standard deviation of the technology shock, σ_z, is estimated at 0.005, while that of the money gwroth shock, σ_g, is estimated at 0.004. This implies that, on average, technology shocks have been more volatile than money growth shocks over the period studied.

5.2 Impulse-Response Analysis

The two sources of fluctuations of the economy around its long run trend in our model are the technology and money transfer growth shocks. I simulate the impact of both, a positive technology shock and a negative money transfer growth shock, on output, prices, nominal wages, hours worked and consumption. The main result of the simulation exercise are the impulse response functions. As previously mentioned, we focus on shocks that put downward pressure on prices given the historic prevalence of downward price rigidity over upward price rigidity.

5.2.1 Technology Shock

Figure 3 depicts the simulated responses of variables in the economy to an unanticipated positive technology shock. As can be seen, a positive technology shock has a contractionary effect on aggregate hours worked and output under the estimated degree of price rigidity. Gali (1999) states that under a scenario of considerable price rigidity, unantipated increases in total factor productivity due to technological innovations will not lead to a reduction in prices as a consequence of price rigidity, and thus aggregate demand will not increase. With the same level of aggregate demand and a greater productive capacity, more can be produced with the same amount of hours worked, and thus the demand for labor is reduced and employment (as measured by hours worked) decreases. Thus, aggregate output decreases on impact, but as prices and nominal wages readjust and fall gradually[27], consumption increases and output recovers. Nonetheless, the effect of this shock on output dissipates within 4 to 5 quarters, and has more persistent effects on prices and nominal wages.

The result of a contractionary effect of a positive technology shock on output and hours worked is a direct result of the relatively large estimate obtained for the average degree of price rigidity. Such a result is in line with those of Marchetti and Nucci (2005). Using firm level panel data for manufacturing firms, these authors find that technological improvements result in contractions of the labor input on impact. Using survey information, they corroborate that the contractionary effect of technology shocks is much stronger for firms that change their prices less often.

Nonetheless, it is important to highlight that due to the existence a positive correlation between output and hours worked, technology shocks might not play an important role in explaining economic fluctuations. Other authors argue that the empirical evidence on the impact of a positive technology shock on hours worked is not very robust (Christiano, Eichenbaum, and Vigfusson (2004), Dedola and Neri (2004), Peersman and Straub (2005)),

[27]Here, nominal wages fall due to the decrease in labor demand, although wage rigidities prevent it from falling further. This results in an even greater reduction in hours worked.

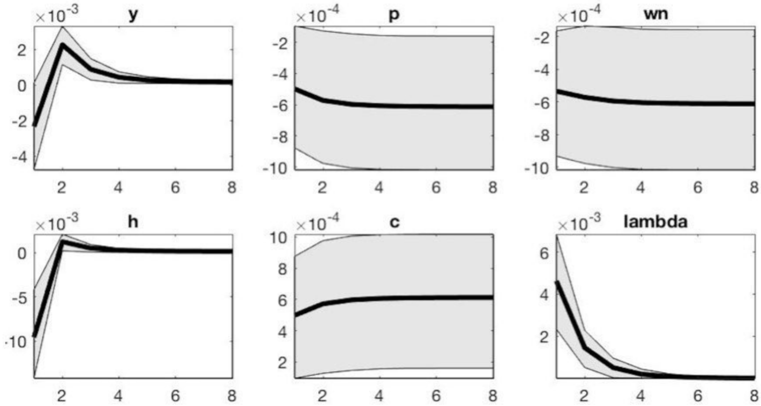

Figure 4: **Estimated responses of variables in the economy to an unanticipated technological innovation.** The figure displays the responses of aggregate real GNP, prices, nominal wages, hours worked, consumption and total factor productivity to a technology shock of magnitude equal to the estimated standard deviation of the shock, along with 90% Bayesian credibility intervals. The responses for each variable are expressed in log deviations of the variable from its long-run trend, given by its steady state.

and thus could be consistent with an increase in hours worked in response to a technological innovation (Smets and Wouters, 2007). In addition, this result is in conflict with the findings of Toledo (2006), whom finds evidence in favor of a positive response of hours worked to an identified positive technology shock in Puerto Rico by estimating a structural VAR with data from the manufacturing sector.

5.2.2 Money Transfer Growth Shock

Figure 4 depicts the estimated responses of variables in the model economy to a negative shock to the growth rate of monetary transfers. This shock can be interpreted as an unexpected reduction in the growth rate of transfers from the federal government to individuals. This constitutes a negative demand shock that is policy-induced.

When there is an unanticipated reduction in the growth rate of federal transfers in our model, there is a reduction in aggregate demand as consumption decreases on impact. This leads, as expected, to a prolonged reduction in output and hours worked. It can be seen that the responses on impact of both, prices and wages, are almost close to zero, as evidenced by the mean response of -0.32 % and the substantial width of the credibility interval, which only provides more evidence of the closeness of the responses to 0. Nonetheless, it can be seen that, although the responses of prices and nominal wages are close to zero, there is a slightly greater reduction in nominal wages than in prices in response to this shock. The estimated reduction of nominal wages on impact is -0.44%, which implies a reduction in nominal wages that is 38% greater than the reduction of prices on impact. The rigidity of wages lead hours worked to fall on impact as a result of the reduction in aggregate demand.

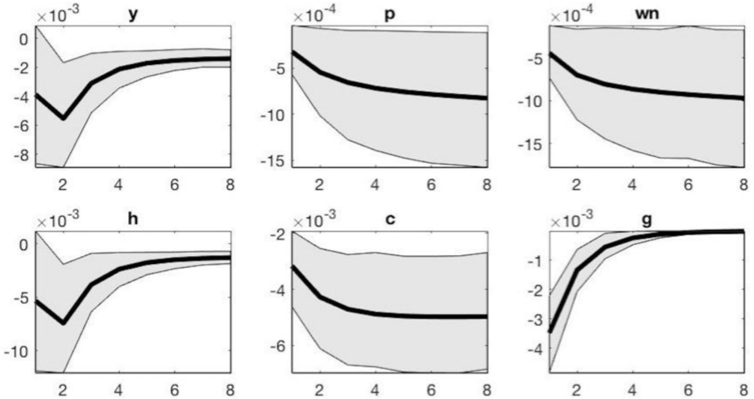

Figure 5: **Estimated responses of variables in the economy to an unanticipated reduction in the growth rate of monetary transfers.** The figure displays the responses of aggregate real GNP, prices, nominal wages, hours worked, consumption and the growth rate of monetary transfers to a negative monetary transfer growth shock. The magnitude of the shock is equal to the estimated standard deviation of the shock, along with 90% Bayesian credibility intervals. The responses for each variable are expressed in log deviations of the variable from its long run trend, given by its steady state.

In particular, the response of aggregate output on impact to an unanticipated reduction in monetary transfers is of 0.4%, which implies a unitary multiplier of monetary transfer growth on output. The credibility bands indicate the possibility that the response of output to this shock is zero on the priod the shock occurs, but they are more suggestive of a larger, negative impact. After the second quarter following the negative monetary transfer shock, output contracts by more and begins to recover after 3 quarters, although it does not return to its pre-shock level. This constitutes evidence that the shock has a permanent effect on economic activity in terms of output and employment, as hours worked do not return to their pre-shock level either.

5.3 Parameter Stability Analysis

In this section, I discuss the results of a stability analysis consisting in the estimation of the model in two subperiods. The first subperiod corresponds to the years ranging from 1980 to 2000, while the second ranges from 2001 to 2019. Given that our data ranges from 1980 to 2019, we consider these partition to be acceptable, as it ensures that there are enough observations in both periods. Table 4 lists the calibrations of the parameters θ and δ for the two sub-periods, which are given by their unconditional means in the two sub-periods. I assume that the markup and discount factor parameters remain constant over both samples.

Table 5: **Calibration of structural parameters for each subperiod**

Subperiod	θ	δ
1980-2000	0.208	0.03
2001-2019	0.33	0.024

In particular, during the first period (1980-2000), the economy of Puerto Rico was charactarized for fluctuating around a positive long run growth trend. In structural terms, this period was characterized for higher deppreciation rates and a lower fraction of aggregate income that went to propietors of capital. During the second period (2001-2019), the economy of Puerto Rico has fluctuated around a negative long run trend. Additionally, this period has been characterized for a higher average fraction of aggregate income that is paid to propietors of capital (lower fraction being paid to labor), and lower average depprecciation rates.

Tables 5 and 6 illustrate the estimates of the model parameters in the two sub-periods.

It can be seen that, during the first subperiod, the parameters corresponding to the average degrees of price and wage rigidity are 0.71 and 0.66, respectively. In the second

Table 6: **Posterior Parameter Estimates: Subperiod 1980-2000**

Parameter	Estimated Posterior Mean	90%	10%
ρ	0.71	0.60	0.83
ρ_w	0.66	0.50	0.84
γ	0.18	0.08	0.28
π	0.46	0.32	0.59
σ_z	0.004	0.002	0.005
σ_g	0.003	0.002	0.004
σ_Y	0.01	0.009	0.012
σ_W	0.009	0.008	0.011
σ_P	0.002	0.0018	0.0026

Table 7: **Posterior Parameter Estimates: Subperiod 2001-2019**

Parameter	Estimated Posterior Mean	90%	10%
ρ	0.85	0.78	0.93
ρ_w	0.60	0.40	0.80
γ	0.46	0.25	0.67
π	0.41	0.22	0.57
σ_z	0.006	0.003	0.009
σ_g	0.0053	0.002	0.008
σ_Y	0.015	0.01	0.021
σ_W	0.005	0.004	0.006
σ_P	0.0024	0.002	0.003

subperiod, the estimate of the price rigidity parameter is greater, at 0.85, while the estimate of the wage rigidity parameter is lower, at 0.60. This implies that prices were less rigid, and thus changed at a higher frequency in the first subperiod relative to the second. In the second subperiod, prices have been more rigid, as the proportion of random firms that do not readjust their prices in any period is higher. This difference in parameter values between the second and first subperiods implies that the average duration of prices was longer by up to 9 months in the second subperiod. At the same time and in contrast, wages were less rigid in the second subperiod relative to the first, and have thus changed at a higher frequency in the second subperiod. Particularly, the proportion of individuals whose wages are not readjusted in any given period is lower. The difference in parameter values between the second and first subperiods implies that the average duration of wages has decreased by 1.3 months from the period they are set to the period when these can be readjusted.

5.4 Phillips Curve Estimation

From the estimates obtained for the average degree of price rigidity and the model expressions that describe the evolution of the price level (equations 21 and 22), it is possible to derive an expression for the growth of the price level in the economy over time. This expression, known as the Phillips Curve, describes how prices evolve at the aggregate level as a function of two factors: expected prices in the future and real marginal costs, since firms in the model set prices as a fixed mark-up over marginal costs[28]. An important element from this equation is its slope, which is a measure of the responsiveness of inflation to changes in real marginal costs in a given period. Since real marginal costs can be a proxy for potential output as real costs increase when production is high relative to productive capacity or its potential level, the slope can as well be interpreted as the responsiveness of inflation to aggregate demand fluctuations.

Table 8 shows the estimates of the curve obtained for Puerto Rico for the two subperiods of 1980-2000 and 2001-2019, and compares it with an estimate of the same measure for the United States derived as an average of the estimates of this parameter in the literature for the US economy. Using the same value of 0.99 for the discount factor β, it can be seen that the estimated slope of the Phillips Curve for Puerto Rico is smaller than for the United States during both of the subperiods studied. This constitutes evidence that Puerto Rico has had a Phillips curve that has been flatter on average than that of the United States during the period studied, and has become even more flat over time as prices have become more rigid. This implies that not only have prices not been as responsive to fluctuations, mainly to contractions, in real costs relative to the United States, but they have become even more unresponsive to such contractions as time has passed. For instance,

[28] Upon substituting (21) into (22), log-linearizing and solving for the period-to-period difference in the deviations of the price level from its long-run trend, one obtains the following log-linear augmented Phillips Curve:

$$\ln P_t - \ln P_{t-1} = \beta[E_t \ln P_{t+1} - \ln P_t] + \frac{(1-\rho)(1-\beta\rho)}{\rho}[(1-\theta)(\ln W_t - \ln W_{ss}) - \ln \lambda_t + \theta(\ln R_t - \ln R_{ss})] \quad (52)$$

Table 8: **Estimates of the slope of the Phillips Curve for Puerto Rico and the United States**

Estimation for:	Estimated Slope of Phillips Curve
United States (up to 2009)	0.22
Puerto Rico (1980-2000)	0.12
Puerto Rico (2000-2019)	0.02

from the estimated slopes it can be seen that for every contraction of 1% in real costs or the output gap, the estimates imply that there was an average reduction of 0.22% in inflation in the United States up to 2009, while for Puerto Rico this average reduction for each 1 percentage point drop in real costs was of 0.12% up to the year 2000, and of 0.02% for the most recent period of 2001-2019. In other words, firms have passed savings from cost reductions to consumers in the form of price reductions at a much lower rate in Puerto Rico when compared to the US over time.

6 Conclusion and Possible Policy Implications

In this paper, I develop and estimate a DSGE model with macroeconomic data from Puerto Rico to study the importance and extent of nominal rigidities and their implications for economic fluctuations in the Island. Using bayesian techniques, I obtain estimates and credibility intervals for the model parameters corresponding to the average degrees of price and wage rigidity in Puerto Rico. The implications of the estimated degrees of rigidity for economic fluctations are analyzed by simulating the impact of unexpected changes in technology and monetary transfers on the model economy. As a check of robustness for our estimates, a stability analysis of our parameters is performed by estimating the model in two subperiods.

The estimation results suggest that, in general, prices in Puerto Rico are more rigid than nominal wages. Particularly, prices take an average of 14 months to change from the time these are set to when they are readjusted, while nominal wages have an average duration of 8 months. Thus, prices can take up to six more months to readjust after nominal wages have readjusted following events that put pressure on both. However, given the historic upward trend in both, prices and nominal wages, it is evident that prices and wages have tended to be significantly more downwardly than upwardly rigid during both subperiods. Overall, this suggests that nominal wages have become more liable to adjust downwards than prices following events that put downward pressure on both, prices and wages, specially contractions in aggregate demand resulting from changes in policy.

Moreover, the results from the stability analysis suggest that prices have been more rigid in more recent years, while wages have been slightly less rigid, and have been far more rigid than in the mainland United States as reflected by the historically higher average share of firms that do not readjust their prices in any given period than that observed for the mainland. This can be seen as well from the estimated slopes of the Phillips Curve for Puerto Rico, which are below the average estimates obtained with a similar calibration for the United States during both of the subperiods, implying prices have been more unresponsive to changes in real costs in Puerto Rico relative to the United States. Thus, events that put pressure, mainly downward pressure, on real costs, such as demand contractions, have resulted in much smaller reductions in prices in Puerto Rico as a greater share of firms do not pass these savings to the consumer in the form of greater price reductions. This is reflective of not only greater relative market power by firms in the Puerto Rican economy, specially at higher levels of the supply chain (importers and local distributors), but of an increase in the concentration of markets (lower business density) and a subsequent increase in such market power over time by individual firms capturing increasingly bigger shares of their respective markets over time.

Overall, these results are suggestive of a strong role of nominal rigidities in exacerbating the magnitude and persistence of economic fluctuations in the Island. Particularly, during downturns in which there is a significant reduction in aggregate demand, prices and wages can take a significant amount of time to readjust downwards. This will imply that the contraction in output will be greater, as business revenue collapses while costs of intermediate goods remain constant, causing aggregate demand to fall by even more. On the other hand, the speed at which nominal wages adjust downwards relative to that of prices suggests a greater degree of market power by firms relative to the bargaining power of individuals in the labor market at the aggregate level. The stability analysis suggests that this pattern has intensified over time, as prices are more rigid and wages are less rigid on average after the 1990's.

It is important to point out some limitations of our analysis. Particularly, according to Nakamura and Steinsson (2013), statistics such as the frequency of price change may be misleading guides to the flexibility of the aggregate price level in a setting where temporary sales, product- churning, cross-sectional heterogeneity, and retailer-manufacturer interactions play an important role. Since we focus on the implications at the aggregate level, we do not taken into account cross-sectional heterogeneity. Additionally, there is much more evidence suggestive of the existence of price rigidity as exacerbator of output contractions, while the same cannot be said with the same amount of certainty with regards to wage rigidity, as the evidence seems to be more split with efficiency wage theories in explaning involuntary unemployment.

An optimal policy in the face of evidence of considerable price rigidity over wage rigidity should first question what the source of such high rigidity is. Given that the literature is more suggestive of greater market power by firms as the principal source of downward price rigidity, an optimal policy in this context would focus on increasing the productivity of or directing more resources to the Antitrust section of the Justice Department, as well as evaluating the possible exemption of the Island from the Jones Act and other laws that extend the average duration of price contracts. On the other hand, evidence of significant downward price and wage rigidity suggest that output and employment are overly sensitive to changes in policy that put downward pressure on prices, such as policies that result in contractions in aggregate demand (Nakamura and Steinsson, 2013). Thus, policy makers should be cautious when considering similar policies and should be aware that the impact of future reductions in monetary transfers on economic activity can be of greater magnitude and persistence than previously thought, and has the potential of having permanent effects on economic activity.

Finally, policies that encourage easing the process of doing business would reduce barriers to entry for smaller, local firms, leading to increased business density and a reduction in monopolistic and oligopolistic behavior across markets. This would not only result in less market power by individual firms and an incentive for these to compete by passing temporary cost savings to consumers in the form of price reductions, but in more bargaining power for workers as new firms would have to offer better salaries and overall working conditions to attract employees.

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7 Appendix

7.1 Equilibrium

The equilibrium of our model consists of a system of 13 equations (equilibrium conditions) and 13 variables, namely C_t, r_t, K_t, M_t, W_t, W_t^*, H_t, h_t^*, P_t, P_t^*, Y_t, z_t and g_t. The equilibrium conditions are given by

$$E_t \frac{P_t}{P_{t+1} c^i_{t+1}} = \beta E_t \frac{P_{t+1}}{P_{t+2} c^i_{t+2}} (r_{t+1} + (1-\delta)) \tag{53}$$

$$k^i_{t+1+j} + \frac{m^i_{t+j}}{P_{t+j}} = \frac{W(i)_t}{P_{t+j}} h^i_{t+j} + r_{t+j} k^i_{t+j} + (1-\delta) k^i_{t+j} + b^i_{t+j} + \Pi_{t+j} \tag{54}$$

$$P_t C_t = g_t M_{t-1} \tag{55}$$

$$W^*(i) = \frac{\psi_w}{\psi_w - 1} \frac{A}{\beta} \frac{E_t \sum_{j=0}^{\infty} (\beta \rho_w)^j \frac{1}{1-h^i_{t+j}} h^i_{t+j}}{E_t \sum_{j=0}^{\infty} (\beta \rho_w)^j \frac{1}{P_{t+1+j} c^i_{t+1+j}} h^i_{t+j}} \tag{56}$$

$$h^i_t = H_t \left[\frac{W_t}{W^*_t(i)} \right]^{\psi_w} \tag{57}$$

$$W_t = [(1-\rho_w)(W^*_t)^{1-\psi_w} + \rho_w (W_{t-1})^{1-\psi_w}]^{\frac{1}{1-\psi_w}} \tag{58}$$

$$M_t = g_t M_{t-1} \tag{59}$$

$$P^*_t(k) = \frac{\psi}{\psi - 1} \frac{E_t \sum_{j=0}^{\infty} (\beta\rho)^i P_{t+i} Y_{t+i}(k) \frac{w_{t+i}}{(1-\theta)\lambda_{t+i}} \left[\frac{r_{t+i}(1-\theta)}{w_{t+i}\theta} \right]^{\theta}}{E_t \sum_{j=0}^{\infty} (\beta\rho)^i Y_{t+i}(k)} \tag{60}$$

$$P_t^{1-\psi} = \rho P_{t-1}^{1-\psi} + (1-\rho)(P^*_t)^{1-\psi} \tag{61}$$

$$\frac{(1-\theta) r_{t+i}}{\theta w_{t+i}} = \frac{H_{t+i}(k)}{K_{t+i}(k)} \tag{62}$$

$$Y_t = z_t K^\theta_t H^{1-\theta}_t \tag{63}$$

$$\ln z_t = \gamma \ln z_{t-1} + \epsilon_t^z \tag{64}$$

$$\ln g_t = \pi \ln g_{t-1} + \epsilon_t^g \tag{65}$$

7.2 Steady State

Given any variable X_t, the steady state implies $X_t = X_{t+1} = X_{ss}$ for all time periods. From the equilibrium condition of the household, we can see that in the steady state,

$$\frac{1}{\beta} = r_{ss} + (1 - \delta) \tag{66}$$

The pricing rule of the intermediate-goods firm simplifies to

$$\frac{\psi}{\psi - 1} = \frac{1}{\frac{w_{ss}}{1-\theta}\left[\frac{r_{ss}(1-\theta)}{w_{ss}\theta}\right]^{\theta}} \tag{67}$$

Thus, the real wage in the steady state are obtained as

$$w_{ss} = \left[\frac{(\psi - 1)(1-\theta)^{1-\theta}\theta^{\theta}}{\psi r_{ss}^{\theta}}\right]^{\frac{1}{1-\theta}} \tag{68}$$

The aggregate version of the hosehold's budget constraint simplifies to

$$\frac{M_{ss}}{P_{ss}} = \frac{W_{ss}}{P_{ss}} H_{ss} + (r_{ss} - \delta) K_{ss} \tag{69}$$

From the wage setting rule of the household rearranged in terms of consumption, we have

$$C_{ss} = \frac{\psi_w - 1}{\psi_w} \frac{\beta}{A} (1 - H_{ss}) \frac{W_{ss}}{P_{ss}} \tag{70}$$

From the cash in advance constraing, we have $P_{ss}C_{ss} = M_{ss}$ (since $g_{ss} = 1$). Combining the wage setting rule in terms of consumption and the cash in advance constraint and substituting in the householdś budget constraint yields

$$\frac{W_{ss}}{P_{ss}}\frac{\psi_w-1}{\psi_w}\frac{\beta}{A}(1-H_{ss}) = \frac{W_{ss}}{P_{ss}}\left[\frac{r_{ss}(1-\theta)}{w_{ss}\theta}\right]^{\theta} Y_{ss} + \frac{Y_{ss}}{\psi} + (r_{ss}-\delta)\left[\frac{r_{ss}(1-\theta)}{\theta w_{ss}}\right]^{\theta-1} Y_{ss} \tag{71}$$

rearranging this expression, we can obtain output in the steady state as

$$Y_{ss} = \frac{\frac{\psi_w-1}{\psi_w}\frac{\beta}{A}\frac{W_{ss}}{P_{ss}}}{\frac{W_{ss}}{P_{ss}}\left[\frac{r_{ss}(1-\theta)}{w_{ss}\theta}\right]^{\theta} + \frac{1}{\psi} + (r_{ss}-\delta)\left[\frac{r_{ss}(1-\theta)}{\theta w_{ss}}\right]^{\theta-1}} \tag{72}$$

substituting into the factor demand functions, we can substitute these in the factor demand functions to obtain the values of capital and hours worked in the steady state, and the steady state of the model is completely characterized.

7.3 Unit root tests

Null Hypothesis: D(P) has a unit root
Exogenous: Constant
Lag Length: 1 (Automatic - based on SIC, maxlag=13)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-2.124597	0.2354
Test critical values:	1% level	-3.473096	
	5% level	-2.880211	
	10% level	-2.576805	

*MacKinnon (1996) one-sided p-values.

Figure 6: **Augmented Dickey Fuler unit root test on the first difference of the implicit GNP deflator.**

Null Hypothesis: D(P,2) has a unit root
Exogenous: Constant
Lag Length: 0 (Automatic - based on SIC, maxlag=13)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-17.03952	0.0000
Test critical values:	1% level	-3.473096	
	5% level	-2.880211	
	10% level	-2.576805	

*MacKinnon (1996) one-sided p-values.

Figure 7: **Augmented Dickey Fuler unit root test on the second difference of the implicit GNP deflator.**

Null Hypothesis: D(WR) has a unit root
Exogenous: Constant
Lag Length: 12 (Automatic - based on SIC, maxlag=13)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-1.464584	0.5488
Test critical values:	1% level	-3.476472	
	5% level	-2.881685	
	10% level	-2.577591	

*MacKinnon (1996) one-sided p-values.

Figure 8: **Augmented Dickey Fuler unit root test on the first difference of real wages.**

Null Hypothesis: D(WR,2) has a unit root
Exogenous: Constant
Lag Length: 11 (Automatic - based on SIC, maxlag=13)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-5.676284	0.0000
Test critical values:	1% level	-3.476472	
	5% level	-2.881685	
	10% level	-2.577591	

*MacKinnon (1996) one-sided p-values.

Figure 9: **Augmented Dickey Fuler unit root test on the second difference of real wages.**

Null Hypothesis: D(Y) has a unit root
Exogenous: Constant
Lag Length: 0 (Automatic - based on SIC, maxlag=13)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-12.97865	0.0000
Test critical values:	1% level	-3.472813	
	5% level	-2.880088	
	10% level	-2.576739	

*MacKinnon (1996) one-sided p-values.

Figure 10: **Augmented Dickey Fuler unit root test on the first difference of real GNP.**